



Application of Synchronous Tree-Adjoining Grammar to Quantifier Scoping Phenomena in English

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Application of Synchronous Tree-Adjoining Grammar to Quantifier Scoping Phenomena in English

A thesis submitted

by

Sean Michael Williford

to

the Department of Linguistics

in partial fulfillment of the requirements

for the degree of Bachelor of Arts with honors.

Harvard College
April 15, 1993

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All the true things in this work are dedicated to my parents. All of the errors are on my head. But any typographical mistakes are the work of the demon Titivillus, who jogged my arm as I was writing.

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0. General Introduction

Within the past ten years, interest has grown in the tree-adjoining grammar (TAG) formalism as a possible metagrammar for natural languages. This paper examines a variant of TAG, synchronous tree-adjoining grammar, which was proposed by Shieber and Schabes (1990) as a means of linking TAG syntactic structures with their corresponding logical forms, among other applications. In particular, the question at hand is whether synchronous TAGs can correctly account for quantifier scoping ambiguities in English sentences containing central NP's, such as (0), and sentences containing complex NP's, such as (1)

- (0) Merrill thought that Carl ate no more than ten pancakes.
- (1) Every performer of some opera pleased most critics.

The work is divided into three chapters. Chapter 1 provides all of the necessary background for understanding the synchronous TAG formalism and its applications to the analysis of quantifiers. It is rather lengthy since the synchronous TAG formalism subsumes much of the work that has been published on TAGs, and I assume no background in TAGs on the part of the reader.

Chapter 2 presents an original argument that no completely satisfactory account of scope ambiguity in sentences containing quantifiers embedded in complex NP's can be fashioned using either of the two current definitions of derivation in synchronous TAGs. Under one definition, the grammar generates the correct scopings at the expense of greatly augmenting the generative power of the formalism. Under the other, the generative power of

the formalism is sufficiently restricted, but this entails that not all of the possible scopings are generated.

Chapter 3 presents the central/normal scoping ambiguities described by Witten(1972) and proposes that the his characterization of the phenomenon is oversimplified. Then a synchronous TAG is presented that can be modified to account for central scopings under either version of centrality. It is noted that modification of the grammar under the revised definition of synchronous TAG derivation is more straightforward than under the original definition, where restriction of the output of the grammar requires somewhat extreme methods.

The work ends with a brief conclusion that summarizes the results and discusses directions for future research.

0.1. A Note on Quantifiers and Quantifier Scope

This paper assumes that the reader has some familiarity with quantifiers and quantifier scoping relations in natural languages, particularly English.¹ By way of a brief review, recall that the term quantifier refers to words that belong to a closed class of nominal determiners, such as *some*, *most*, *all*, *every*, *one*, *two*, and *three*. The notion of quantifier scoping is illustrated in the ambiguity of the following sentence:

- (2) Some Viking owns every longship.

¹ For earlier linguistic accounts of quantifier scope ambiguity, see Montague (1974), May (1990), and Cooper (1983), although knowledge of their approaches is not needed for understanding the current work.

Sentence (2) has two possible meanings: The sentence could be interpreted as asserting the existence of one particular Viking, who happens to own every longship in the world. In this case, we say that the quantifier *some* of *some Viking* has wide scope over the *every* of *every longship* and that *every* is hence within the scope of *some*. .

Alternatively, one could interpret the sentence as asserting that for every longship in the world, there exists some Viking who owns it. In this case, there could exist more than one Viking, in fact each longship could be owned by a different Viking. This is the reading where *every* has wide scope over *some*, and so *some* is said to be within the scope of *every*.

Put into a predicate calculus form, these two readings can be rendered as

- (3) a) $\exists x(\text{viking}(x) \wedge \forall y(\text{longship}(y) \Rightarrow \text{owns}(x,y)))$
 b) $\forall y(\text{longship}(y) \Rightarrow \exists x(\text{viking}(x) \wedge \text{owns}(x,y)))$

where the scoping relations are made explicit in the nesting of the quantified expressions.

1. Tree-Adjoining Grammars and Synchronous TAGs

1.1. Overview

This chapter is essentially an introduction to various aspects of tree-adjoining grammars (TAGs), directed toward the eventual explanation of the synchronous tree-adjoining grammar formalism that is the focus of this paper. The presentation is tailored to the reader with a background in linguistics who has some familiarity with terms and concepts in formal language theory.

Following this section, a brief account is given of the interest in using TAGs to account for phenomena in natural language syntax. Then the basic TAG formalism is defined, with an example for a fragment of English. The lexicalized and multi-component variants of TAG are then described, which are employed within the synchronous TAG approach to quantifiers. Finally synchronous TAGs themselves are introduced as a means of augmenting TAGs to simultaneously generate syntactic structures and their corresponding semantics. The chapter closes with an account of Shieber and Schabes' (1990) approach to handling sentences with quantifier scope ambiguity in a synchronous TAG framework.

1.2. Motivation for the Linguistic Application of Tree-Adjoining Grammars

Tree-adjoining grammars (TAGs) were introduced as a mathematical formalism by Joshi, Levy, and Takahashi (1975). Studied originally for their

mathematical properties, developments within natural language research in the 1980's indicated that the generative power and particular properties of the TAG formalism might make it ideal for the representation of structures in natural languages.

Working to formally and rigorously constrain the power of generative grammars for natural language, Gazdar (1982) proposed a variant of context-free phrase-structure grammar for analyses of syntax. One of his primary reasons for moving away from models involving transformational grammars was that the mathematical properties and constraints of transformational grammars (TGs) were largely unknown, whereas the properties of context-free grammars (CFGs) had been extensively researched and were well understood. In addition, Pullum and Gazdar (1982) exposed fatal flaws in all of the arguments for the non-context-freeness of natural language that had been published up to that point. Thus, it seemed that there was no well-established need to employ any formalism more powerful than context-free grammars in the analysis of natural language.

However, subsequent research, particularly Shieber (1985) and Culy (1985), offered evidence against the weak context-freeness² of natural language; and Bresnan, et al. (1982) argued that natural language is not strongly context-free in their account of cross-serial dependencies in Dutch. In light of these developments, interest grew in TAGs because they are more powerful than context-free grammars³ and are well-characterized in terms of their mathematical properties. Moreover, the slight power advantage TAGs

² As discussed by Culy (1985), the weak generative capacity of a language refers to the complexity of the set of strings in that language. Thus, a given string language is weakly context-free if its string set can be generated by some context-free grammar. Strong generative capacity refers to the complexity of the set of structures assigned to strings in that language. A language is strongly context-free if the structures assigned to the strings can be produced via derivation in some context-free grammar generating the string set.

³ The power of the TAG formalism is more fully discussed in section 1.3.6.

possess compared to CFGs seems to be of just the right sort for characterizing non-context-free constructions in natural languages. This hypothesis was first proposed by Joshi (1985 [1983]), who supported it by showing a nontransformational TAG account of the Dutch data in Bresnan, et al.

Kroch and Joshi (1985) followed, more explicitly demonstrating the linguistic application of TAGs to phenomena such as Wh-movement and raising constructions. TAGs are particularly well-suited to accounting for unbounded dependencies such as subcategorization and filler-gap, due to the factoring of dependencies and recursion in the formalism (Joshi 1985 [1983]). In a TAG, all dependencies are defined on a finite set of finite initial structures. Recursion is a consequence of the adjunction operation for composing trees, which preserves these dependencies in a derivation.⁴

Shieber and Schabes (1990) introduced the synchronous TAG formalism as a means of formally linking expressions in two languages, where each language is defined by a TAG grammar. In particular, synchronous TAGs enable the addition of semantics to TAG syntactic analyses, and the current work focuses on the application of this formalism to account for quantifier scope ambiguities in a TAG framework.

1.3. Introduction to Tree-adjoining grammars

In this section I will largely follow Joshi (1985) and Joshi (1987) in the definition of a tree-adjoining grammar, augmenting his schematic diagrams with examples from a TAG for a fragment of English. Much of this material can also be found in Joshi, Vijay-Shanker, and Weir (1991). The formal

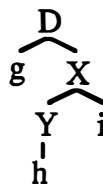
⁴ TAGs with local dependencies or 'links' defined on the elementary trees fall outside the scope of this paper. The adjunction operation is defined in section 1.3.2.

definition of basic TAGs is followed by discussion of the adjunction operation, derivation in a TAG, derivation trees, tree sets and string languages of TAGs, and the generative power of the formalism.

1.3.1 Definition of a TAG

Formally, a tree-adjoining grammar G is a pair (I, A) where I and A are finite sets of elementary trees (Joshi, 1985). Trees in I are called the **initial** trees and trees in A are called the **auxiliary** trees. A tree α is an initial tree if the root node of α is S , the start symbol for the grammar, and if all of the frontier nodes⁵ of the tree are terminals. All of the internal nodes must be non-terminals. Such a tree will have the form illustrated in Figure 1, borrowed from Joshi (1987):

⁵ To avoid confusion between terminal nodes and terminal symbols, I have followed Joshi's convention of using the term "frontier nodes" for those nodes which do not dominate any other nodes in the tree. These nodes are also commonly referred to as the terminal nodes or the 'leaves' of the tree. All nodes in the tree which do dominate other nodes are referred to as internal nodes. Thus, in the following tree the nodes labeled by D , X , and Y are internal nodes and those labeled by g , h , and i are frontier nodes.



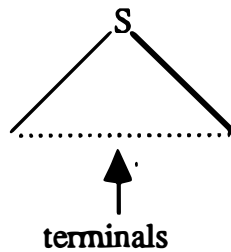


Figure 1: Schematic of a TAG initial tree (Joshi,1987)

A tree β is an auxiliary tree if the root node of the tree is some non-terminal X , and the frontier of the tree consists of terminals and one occurrence of non-terminal X , which is called the **foot node** of the tree. Just as in an initial tree, all of the internal nodes of an auxiliary tree must be non-terminals. Such a tree β is diagrammed in Figure 2:

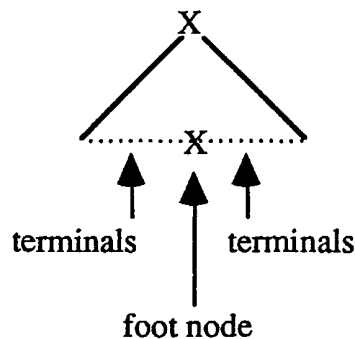


Figure 2: Schematic of a TAG auxiliary tree (Joshi, 1987)

A TAG consists of nothing more than a set of auxiliary trees and a set of initial trees. For example, a TAG G_1 for a simple subset of English is given

in Figure 3 below.⁶ The lone initial tree takes the form of an entire simple sentence, and the auxiliary tree represents the structure of an adverb modifying the verb phrase

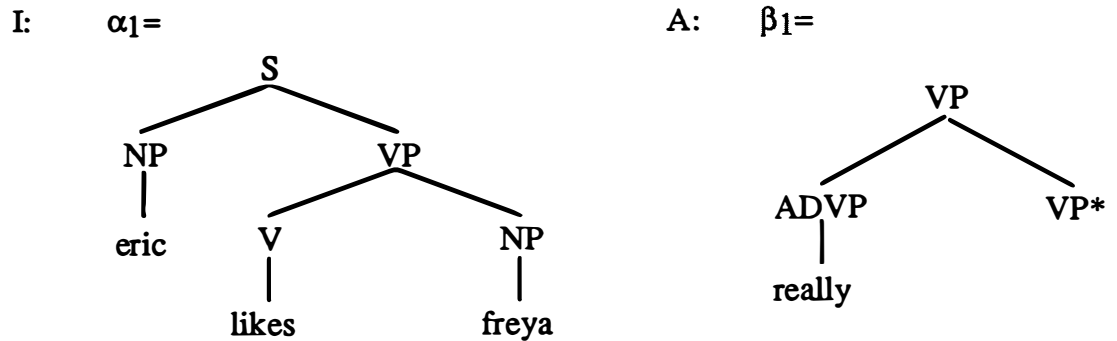
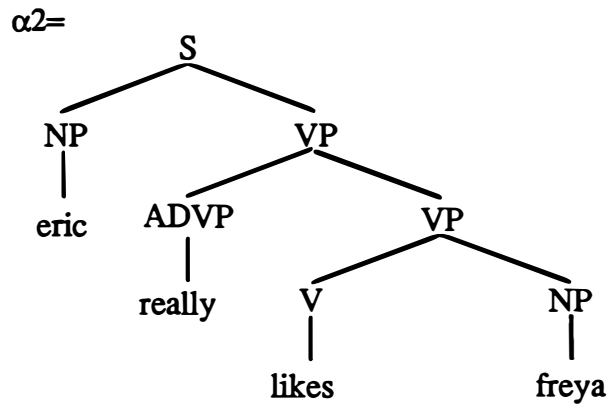


Figure 3: A sample TAG $G_1 = (I, A)$ for a fragment of English

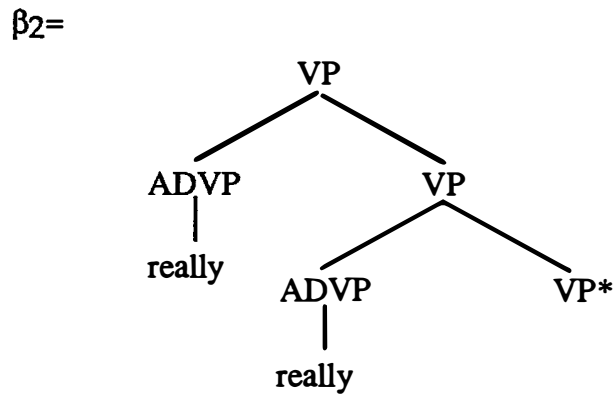
Other than the properties mentioned above, the two tree types are unconstrained. However, ideally both the initial and the auxiliary trees are "minimal" (Joshi, 1987). Initial trees should correspond to minimal sentential structures which do not recurse on any non-terminal. The initial tree α_1 in Figure 3 is thus well-formed with regard to this constraint, whereas α_2 below is not, since there is recursion on the VP symbol within the tree.⁷

⁶ In this and all subsequent examples, I will use capital letters to represent non-terminal symbols and lower-case letters to represent terminals.

⁷ α_2 is actually a derived tree resulting from the composition of α_1 and β_1 . See section 1.3.2. for details of the compositional operation, and section 1.3.3. for discussion of derivation in a TAG.



In a similar way, a given auxiliary tree rooted in X should correspond to the minimal recursive structure required in a derivation if one recurses on X . Tree β_1 in Figure 3 is minimal in the intended sense, but tree β_2 below is not, since recursion on VP occurs within the tree.⁸



1.3.2. The Adjunction Operation

The production of derived structures in a TAG relies on only one operation, adjunction (Joshi, 1987). Adjunction composes an auxiliary tree β

⁸. β_2 is a derived tree resulting from the composition of two copies of β_1 using adjunction. See footnote 8. for further discussion of this particular tree.

with some other tree σ in the following way: Let σ be a tree containing the non-terminal X at node position n , and let β be an auxiliary tree rooted in X . The adjunction of β to σ at node n is a tree σ' , which is the result of the following operation:

- a) Let t be the subtree in s dominated by n
Excise t , leaving a copy of n behind.
- b) Attach β to σ less t at node n , and identify the root of β with n .
- c) Attach t to the foot node of β , and identify the root node n of t with the foot node of β .

Figure 4 diagrams the generalities of this operation.

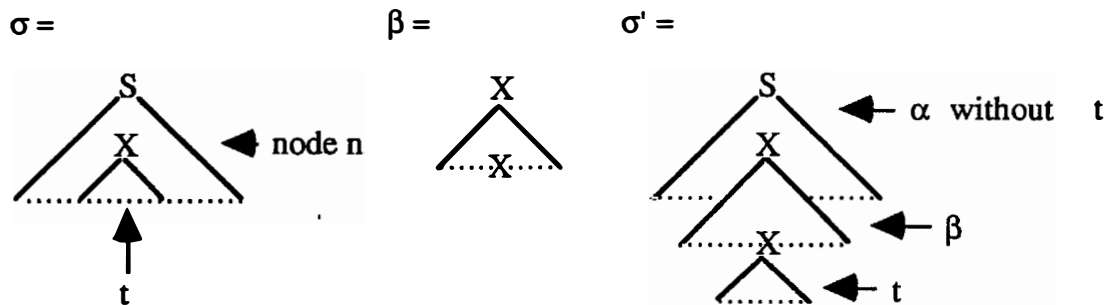


Figure 4: Schematic diagram of adjunction (Joshi, 1987)

Note that adjunction is not a substitution operation, although it can simulate the effect of substitution in certain cases.⁹

⁹. Adjunction and substitution have the same effect only when the adjunction is such that the root of the auxiliary tree dominates the root of the original tree in the derived structure. For example, the tree β_2 considered in section 1.3.1. was derived by adjoining β_1 to the root of another copy of β_1 . This is equivalent to substituting a copy of β_1 at the foot of β_1 .

Joshi (1987) comments on this point in somewhat looser terms, characterizing operation-ambiguous trees such as β_2 as derived structures in which the auxiliary "sits on top of" the original tree.

For a more concrete example of adjunction, consider the TAG from Figure 3. The process of adjoining β_1 into α_1 at the node labeled by VP is illustrated in Figure 5 below. For clarity, the subtree corresponding to t in Figure 4 has been boxed. The result of the derivation, α_1' , was rejected as an initial tree in section 1.3.1. because the recursion on VP violated the minimality requirement for initial trees. The reason for such a requirement should now be apparent. In a properly constructed TAG, recursion on non-terminals is accomplished solely through adjunction of auxiliary trees. Thus, any tree exhibiting such recursion must be considered a derived structure, and cannot be an elementary tree of the TAG.

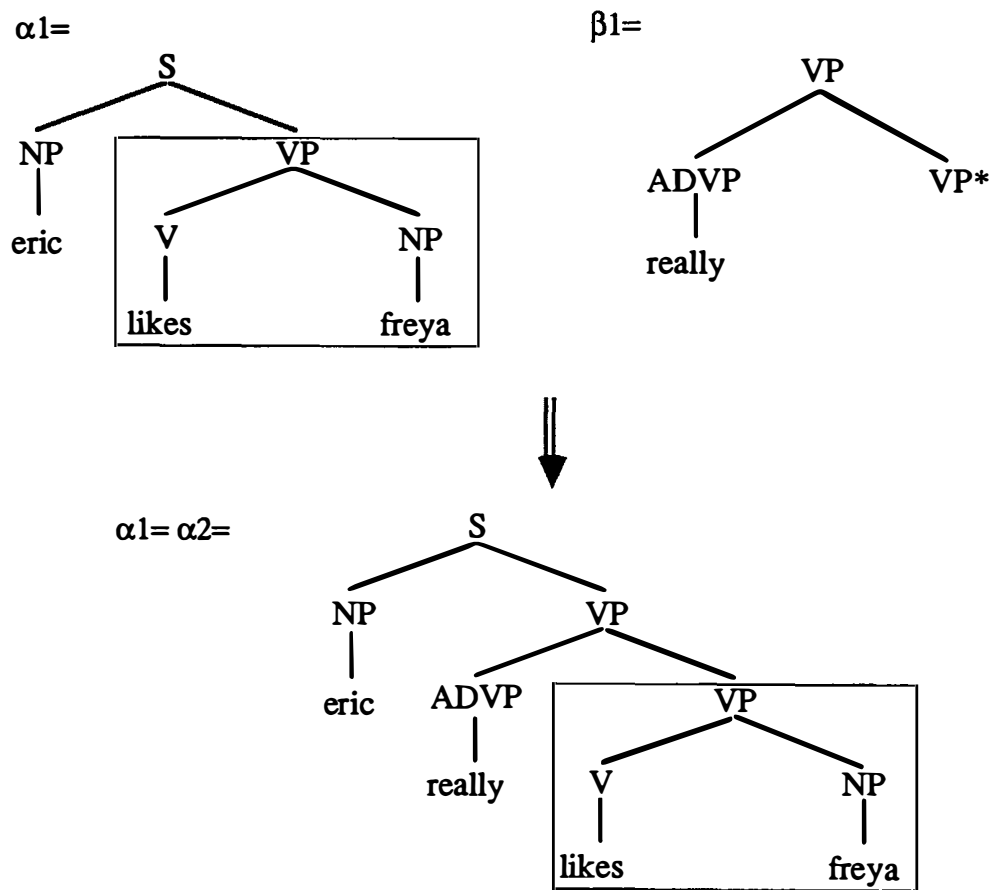


Figure 5: Example of adjunction

1.3.3. Derivation in TAGs

In this section we will consider the standard definition of derivation in TAGs, which is especially relevant to the argumentation in chapter 2. For the time being, we will put aside the TAG G_1 for a fragment of English and consider instead a TAG G_2 for the regular language $L = \{w \mid w = g^*h^+f^+\}$ ¹⁰, which is depicted in Figure 6.

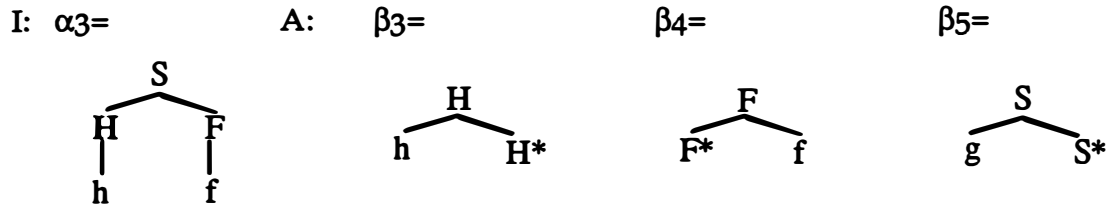
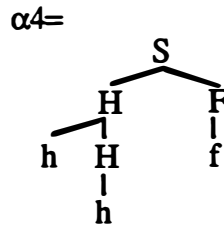


Figure 6: a TAG $G_2 = (I, A)$ for $L = \{w \mid w = g^*h^+f^+\}$

Recall that adjunction is defined on some auxiliary tree β , an elementary tree α , and an address node n of α . Thus, it only makes sense to talk about adjunctions of auxiliary trees to elementary trees. Adjunction at an address in a derived structure is not allowed (Joshi, 1987). If one wanted to derive the structure for the string $hhhf$ in $L(G_2)$, one might start by adjoining β_3 at the node labeled by H in α_3 . This yields the string hhf and the tree α_4 .

¹⁰. The notation is standard for formal languages. L is the infinite set of strings that contain zero or more g 's, followed by one or more h 's, followed by one or more f 's. The shortest string in the language is therefore hf .



However, the derivation of *hhhf* is now stalled. Since adjunction is undefined for addresses in a derived structure, derivation cannot proceed by adjunction of β_3 into α_4 .

So, in order to generate *hhhf*, one must ensure that at each step of the derivation, the necessary adjunction is possible under the definition given in 1.3.2. In this case, there is only one possible derivation. One must first adjoin β_3 to the root node of another β_3 tree. Then, this derived tree is adjoined to α_3 at the node labeled with the H symbol, completing the derivation. This process is diagrammed in Figure 7. The composite arrows are intended to indicate that the structure to the left of the arrow is adjoined into the structure below the arrow.

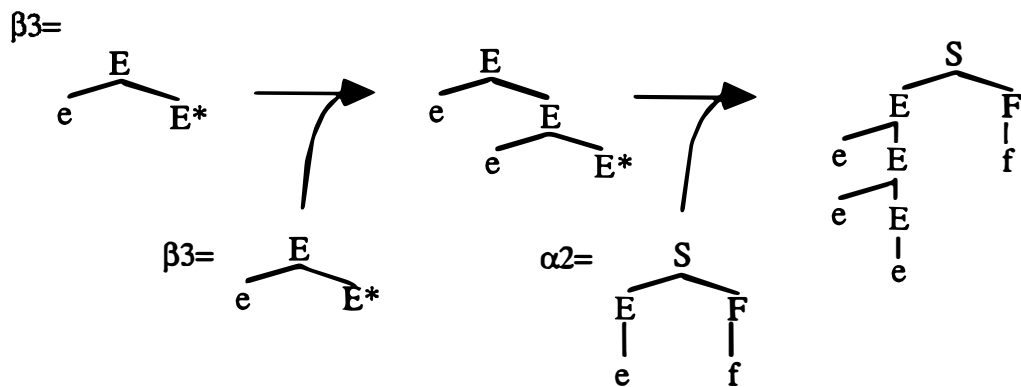
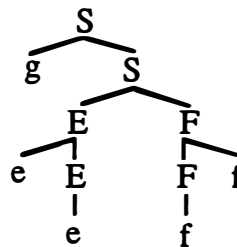


Figure 7: Derivation of the structure corresponding to *hhhf* in G2

TAG derivation is thus a process of adjoining elementary or derived auxiliary trees with elementary trees. This often results in the counterintuitive process of adjoining a large, complex auxiliary tree into a relatively simple elementary tree, but it is an inevitable consequence of the definition of the adjunction operation.

One further derivational consideration is that adjunction of more than one auxiliary tree to an elementary tree is permitted, as long as each adjunction occurs at a distinct node (Joshi, 1987). Thus, we can straightforwardly derive the string *ghhff* using our TAG G_2 by simply adjoining β_5 into α_3 at the node labeled with S, adjoining β_3 into α_3 at the node labeled with H, and adjoining β_4 into α_3 at the node labeled with F. These adjunctions may occur in any order, yielding α_5 .

$\alpha_5 =$



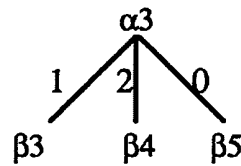
1.3.4. TAG Derivation Trees

A derivation tree for a TAG is a structure that specifies how a given derived tree was produced (Joshi, 1987). The root of the derivation tree is labeled by an initial tree. All other nodes are labeled with auxiliary trees. The edges connecting parent nodes to children are labeled with addresses in the parent trees at which the children were adjoined. Tree addresses are given as Gorn addresses (Gorn, 1965): the root node lies at address zero, k is the address

of the k^{th} child of the root node, and $p \bullet q$ is the address of the q^{th} child of the node at address p (following a convention of Schabes, 1991, p. 10).

For example, consider the following derivation tree D_1 for the tree α_5 mentioned above.

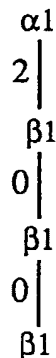
D_1 :



The derivational structure implicitly describes the derived tree it generates. The result of the derivation in D_1 has β_3 adjoined into address 1 (E) of α_3 , β_4 adjoined into address 2 (F) of α_3 , and β_5 adjoined into address 0 (S) of α_3 . In other words, the tree α_5 .

Returning again to our English example G_1 , consider the derivation of the sentence "Eric really really really likes Freya." The first step would be to adjoin β_1 into β_1 at its root. Then this derived structure is adjoined into a third copy of β_1 at its root. Finally, this structure is adjoined into the α_1 initial tree at address 2 (V). The derivation tree D_2 of this sentence mirrors this process.

D_2 :



It is possible to think of the definition of derivation given in section 1.3.3. in terms of well-formedness conditions on derivation trees. For this purpose I adopt the following notation adapted from Shieber (1992): In a given derivation tree, a node η is referred to by its Gorn number in the tree. The parent node of a node η (the node which immediately dominates η) is notated $\text{parent}(\eta)$. The tree that the node η marks the adjunction of is written as $\text{tree}(\eta)$. The arc between node η and $\text{parent}(\eta)$ is labeled with an address in $\text{tree}(\text{parent}(\eta))$ where the adjunction of $\text{tree}(\eta)$ takes place. This address is notated as $\text{addr}(\eta)$. The root node of the tree has no parent or arc address associated with it.

For example, in derivation tree D2 above, node 0 in the tree is the root node. $\text{tree}(0)$ is $\alpha 1$, and $\text{parent}(0)$ and $\text{addr}(0)$ have no defined values. Node $1 \bullet 1 \bullet 1$ is the bottom-most node in the tree. $\text{tree}(1 \bullet 1 \bullet 1)$ is the tree which labels the node, namely $\beta 1$. $\text{parent}(1 \bullet 1 \bullet 1)$ is node $1 \bullet 1$, the node which immediately dominates $1 \bullet 1 \bullet 1$. $\text{addr}(1 \bullet 1 \bullet 1)$ is the address which labels the arc between node $1 \bullet 1 \bullet 1$ and its parent, which in this case is 0. Thus, this notation describes nothing new, but rather allows us to precisely refer to information which is present in the derivation tree.

With this notation in hand, one can specify a valid derivation of a TAG G as one for which the derivation tree meets the following conditions:

- a) $\text{tree}(0)$ (the tree associated with the root node) is an initial tree;
- b) For each arc in the tree from a node η to $\text{parent}(\eta)$ labeled by $\text{addr}(\eta)$, $\text{tree}(\eta)$ is an auxiliary tree that can adjoin into $\text{tree}(\text{parent}(\eta))$ at $\text{addr}(\eta)$;
- c) If a node η has siblings, the $\text{addr}(\eta_i)$ for each sibling η_i is distinct.

Any derivation tree which does not meet the above criteria is considered ill-formed and does not represent a valid derivation in G .

This characterization of derivation does not differ substantively from the account given in section 1.3.3. Condition a) ensures that the derived tree corresponding to a given derivation in a TAG G is a member of the tree set of the grammar $T(G)$ (defined and discussed in section 1.3.5.). Condition b) invokes the definition of adjunction, making sure that adjunction of an auxiliary tree only occurs into a compatible node (i.e. the label of the adjunction site matches the foot node label of the auxiliary tree). Condition c) ensures that multiple adjunctions do not occur at a single node in a tree.

Note that we do not have to specify that adjunction occurs only into elementary trees. All nodes in a derivation tree can only be labeled by elementary trees. Thus, the adjunctions indicated by arcs between nodes are always adjunctions of some auxiliary tree into an elementary tree. As noted by Vijay-Shanker (1987), the derivation tree presents the derivation of a given structure in terms of an inside-out process. Looking at the derivation tree from the bottom up, first auxiliary trees are adjoined into other auxiliary trees to form derived auxiliary trees. These structures are then adjoined into other elementary trees to form new derived structures, and so forth, until adjunction occurs into an initial tree, ending the derivation.

1.3.5. Tree Sets and String Languages of TAGs

When dealing with TAGs, it is often convenient to discuss different aspects of the generative output of a given grammar. If $G = (I, A)$ is a TAG as defined in the preceding sections, then the **tree set** of G , $T(G)$, is the set of all trees that can be derived from initial trees in I using auxiliary trees in A and the adjunction operation. The **string language** of G is the set of all the terminal strings of the trees in $T(G)$ (Joshi, 1987).

For example, TAG G_1 for a fragment of English has the string language $L(G_1) = \{w \mid w = ab^*cd, a = \text{"Eric"}, b = \text{"really"}, c = \text{"likes"}, d = \text{"Freya"}\}$. Thus, G_1 generates the strings "Eric likes Freya", "Eric really likes Freya", "Eric really really likes Freya", and so forth. The language is infinite because there can be an arbitrary number of "really"s between "Eric" and "likes." The tree set $T(G_1)$ is the set of the actual derived trees which correspond to the strings in $L(G_1)$.

1.3.6. Formal Power of TAGs

The class of languages generated by TAGs, the Tree-Adjoining Languages (TAL), form a full abstract family of languages quite restricted in scope (Joshi, 1987). A pumping lemma for TALs has been established by Vijay-Shanker (1986), which restricts the class specifically. TALs properly contain the context free-languages, and are properly contained within the indexed languages, which themselves are properly contained within the context-sensitive languages (Schabes, 1991 p.31). The additional power TAGs possess compared to context-free grammars is highly constrained to only certain types of long-distance dependencies, which are no more than local dependencies defined on elementary trees that become stretched-out as a result of adjunction (Joshi, 1985).

In Joshi, Vijay-Shanker, and Weir (1991), the class of mildly context-sensitive grammars (MCSG) containing TAGs is loosely defined in terms of a set of minimal conditions that a generated language (MCSL) must satisfy. The membership of this class was expanded beyond TAGs in light of research that proved that several other formalisms, such as head grammars, linear

indexed grammars, and combinatorial categorical grammars, are equivalent to TAGS.

1.4. Lexicalized Tree-Adjoining Grammars

Lexicalized tree-adjoining grammars are variants of the TAG formalism that are often applied to the analysis of natural language. This section will first define the formalism and the new operation of substitution, and then move on to derivational issues and an example lexicalized TAG for a fragment of English. Most of the material presented in this section has been drawn from Schabes (1991).

1.4.1. Definition of a Lexicalized TAG

As discussed by Schabes (1991, p.2-3), a lexicalized grammar is a formalism which consists of a finite set of structures of finite size, each of which is systematically associated with at least one lexical item. This item¹¹ is called the anchor of the structure, and it is freely chosen. Thus, the structure specifies the local domain over which constraints associated with the anchor are defined. Structures are composed using one or more operations which must combine a finite set of structures into a finite number of structures.

Lexicalized TAGs are tree-adjoining grammars which meet the above specifications. Schabes (1991, pp.26-7) proves that TAGs are closed under

¹¹. Actually, the anchor of a structure does is not limited to only a single lexical item. If more than one lexical item appears in the elementary structure, then a subset of the lexical items can be designated the multi-component anchor of the structure. Schabes (1991, pp.49-50,52-7) cites usage of such structures in developing a lexicalized TAG for English, but these considerations go beyond the scope of the current work.

lexicalization, so this modification does not extend the power of the formalism beyond the tree-adjoining languages. For the definition of a lexicalized TAG, we will make explicit a number of features of regular TAGs which were implied but not directly stated in the definition in section 1.3.1.

Schabes (1991, pp15-6) defines a lexicalized TAG as a quintuple (Σ, NT, I, A, S) where

- (i) Σ is a finite set of terminal symbols;
- (ii) NT is a finite set of non-terminal symbols such that $\Sigma \cap NT = \emptyset$;
- (iii) S is a distinguished non-terminal symbol: $S \in NT$;
- (iv) I is a finite set of finite trees (the initial trees) such that for each tree α in I ,
 - all interior nodes of α are labeled with non-terminal symbols;
 - at least one frontier node of α must be labeled with a terminal symbol (the anchor), other frontier nodes are labeled with terminals or non-terminals;
 - non-terminal symbols on the frontier of α are marked for substitution; by convention, a substitution site is notated by a down arrow (\downarrow).
- (v) A is a finite set of finite trees (the auxiliary trees) such that for each tree β in A :
 - all interior nodes of β are labeled with non-terminal symbols;
 - at least one frontier node of β must be labeled with a non-terminal symbol (the anchor), other frontier nodes are labeled with terminals or non-terminals marked for substitution, except for one node labeled by a non-terminal, the foot node, which is marked with an asterisk (*);

- the label of the foot node of β must be identical to the label on the root node.

Let us compare this definition with the definition of TAGs stated in section 1.3.1. Both Σ and NT are implicit in the original formulation of TAGs. S is the symbol which is the start symbol for TAGs-- every initial tree is required to be rooted in S . In lexicalized TAGs this strong requirement on initial trees does not exist. Instead, S is a marked symbol that plays a special role in derivation, which is the subject of the next section.

The elementary tree sets I and A of the lexicalized TAG are essentially the same as the TAG counterpart sets defined in 1.3.1. In particular, trees in I and A should meet the requirements of minimality discussed in section 1.3.1.¹² However, there are two major differences between the plain TAG and the lexicalized TAG tree sets. First, as was noted above, initial trees do not have to be rooted in S . In fact, the choice of root node for a given initial tree is unconstrained within the set of non-terminals. Second, the frontiers of elementary trees are not restricted to terminals only (or terminals plus a foot node, in the case of an auxiliary tree). Both terminals and non-terminals can be placed on the frontier, as long as at least one terminal symbol is specified as the lexical anchor of the tree.

In addition, all frontier non-terminal symbols in an elementary tree must be marked for substitution, which is an additional compositional operation of the grammar. Although we mentioned in section 1.3.2. that adjunction alone can mimic the effect of substitution, Schabes (1991, pp27-8)

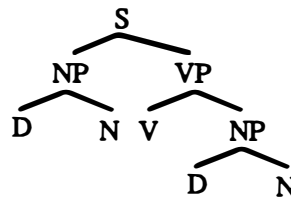
¹². There is also a semantic minimality requirement proposed by Schabes (1992? p28), which is discussed in Footnote 12.

argues convincingly for the inclusion of substitution as an additional operation on both formal and linguistic grounds.¹³

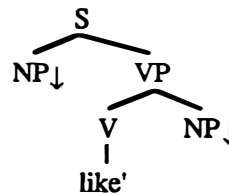
1.4.2. The Substitution Operation

Substitution composes a tree α with an elementary tree σ in the following way: Let α be an initial tree, or a derived tree generated from an initial tree, which is rooted in a non-terminal X . Let σ be an elementary tree which has a substitution node (indicated by \downarrow) on its frontier labeled with the non-terminal X . Tree α is substituted into tree σ by taking the substitution

¹³. Formally, a lexicalized TAG with substitution can be represented in a more compact fashion than an equivalent grammar using only adjunction. Linguistically, the adjunction-only TAGs that Kroch and Joshi (1985) propose for sentences in English leave much to be desired in terms of the semantic compositionality of the structures. In Kroch and Joshi's examples, the elementary tree for a two-place predicate such as the transitive verb *like* has all of the constituents expanded up to the preterminal nodes. Below are is a sample initial tree corresponding to the argument structure of *like*:



Schabes finds this analysis is unsatisfying because the intuition is that a verb like *like* semantically takes two arguments, which are rendered syntactically as NP's. This generalization is lost in the above trees, since they are expanded all the way to the level of the preterminal nodes. According to Schabes, elementary trees ought to correspond to minimal semantic units, as well as minimal syntactic units. Such a condition can be met in a lexicalized TAG employing substitution, which could assign the following category structure to *like*:



In this case, the subcategorization requirements of *like* are transparently built into the domain of the initial tree it anchors. *Like* takes two arguments, which are of the NP category.

node on tree σ 's frontier and replacing it with the root of α . A schematic portrayal of substitution of α into σ is given in Figure 10.

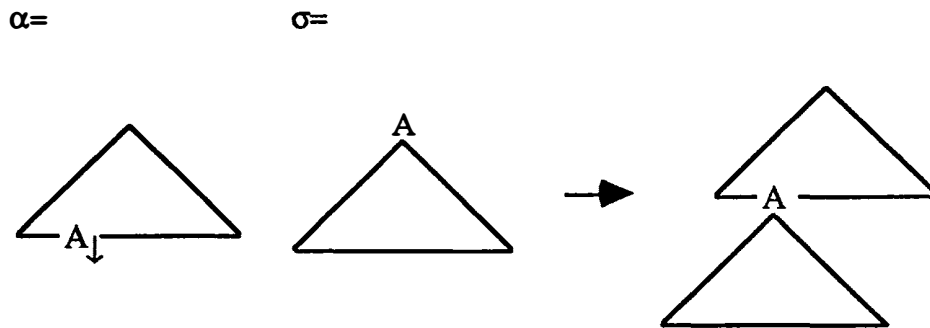


Figure 10: Schematic diagram of substitution (Schabes, 1991, p7)

1.4.3. The Adjunction Operation

The adjunction operation for lexicalized TAGs is the same as the adjunction operation defined in section 1.3.2. for the basic TAG formalism.

1.4.4. Derivation in a Lexicalized TAG

Since substitution is defined as only operating on nodes in elementary trees, the derivation of a complex structure in a lexicalized TAG essentially follows the procedure for TAGs discussed in section 1.3.3. Each step of the derivation involves inserting some tree at an address in an elementary tree by performing an elementary operation, which could be either adjunction or substitution.

The derivation trees for lexicalized TAGs look slightly more complex, since they must record whether the composition of a given pair of trees is a result of substitution or adjunction. This is notated by using solid lines to indicate adjunction, and broken lines to indicate substitution (see example in 1.4.6). Additional constraints on the well-formedness of derivation trees for lexicalized TAGs are discussed in section 1.4.5. below.

1.4.5. Tree Sets of Lexicalized TAGs

The tree set $T(G)$ of a lexicalized TAG G must be defined in terms of two requirements which are met automatically by derived structures in a basic TAG:

A derived tree σ is a member of the tree set $T(G)$ of a lexicalized TAG G if and only if

- (i) σ is rooted in the distinguished non-terminal S ; and
- (ii) The frontier of σ consists entirely of terminal symbols.

Condition (i) compensates for the fact that not all initial trees in a lexicalized TAG are rooted in S . In order to preclude overgeneration, it is necessary to filter out derived structures which do not correspond to full expressions of the tree language of G , i.e. trees which are not rooted in S . Overgeneration of this sort cannot occur in a regular TAG, since all initial trees are rooted in S . Derivation preserves this property, and so all derived trees are rooted in S .

Condition (ii) simply requires that all nodes labeled as substitution sites must be operated on before derivation is concluded. A derived structure with

extant substitution sites on its frontier is not a well-formed expression of the tree language of G . This issue never arises in a regular TAG, since there is no substitution.

These conditions on membership in the tree set could also be stated as conditions on the well-formedness of derivation trees for a lexicalized TAG G , as was done in section 1.3.4. The criteria list for lexicalized TAG is as follows:

- a) $\text{tree}(0)$ of the derivation tree is an S-type initial tree;
- b) For each arc in the tree from a node η to $\text{parent}(\eta)$ labeled by $\text{addr}(\eta)$, $\text{tree}(\eta)$ is an auxiliary tree that can adjoin into $\text{tree}(\text{parent}(\eta))$ at $\text{addr}(\eta)$, or $\text{tree}(\eta)$ is an initial tree that can substitute into $\text{tree}(\text{parent}(\eta))$ at $\text{addr}(\eta)$;
- c) If a node η has siblings, the $\text{addr}(\eta_i)$ for each sibling η_i is distinct;
- d) If $\text{tree}(\eta)$ contains j substitution nodes at addresses $a_0..a_j$, then there must be j substitution arcs from η to daughter nodes $\eta_0..\eta_j$, such that the label $\text{addr}(\eta_i)$ of arc i is a_i .

Any derivation tree which fails one of the above criteria does not represent a valid derivation in G , and so the corresponding structure is not an element of $T(G)$.

1.4.6. A Simple English Example

Figure 11 contains some elementary trees from a lexicalized TAG for English.

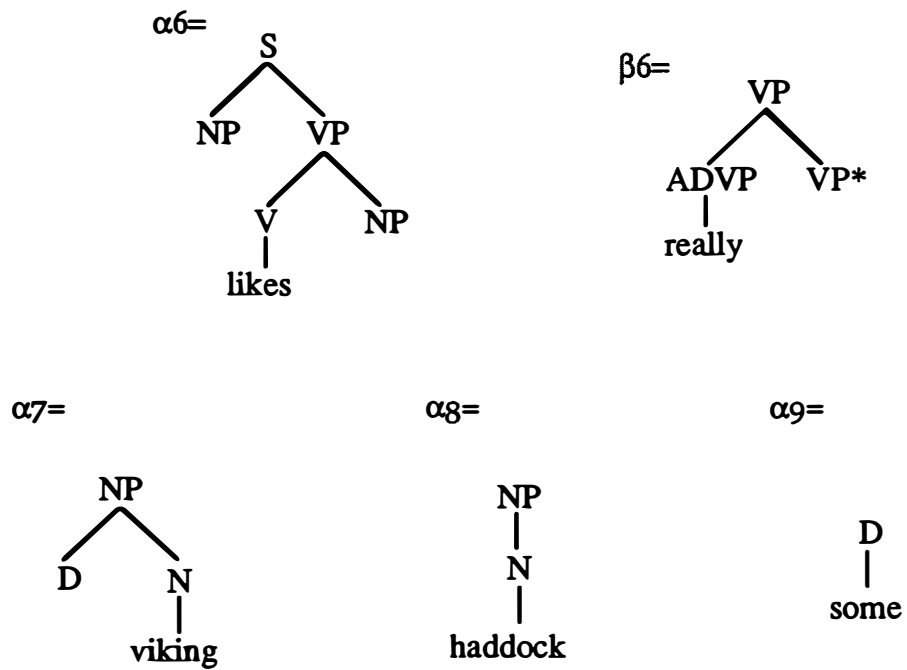


Figure 11: Some elementary trees from a lexicalized TAG for English

These trees can be used to derive the tree α_{10} for the sentence "Some Viking really really likes haddock," below.

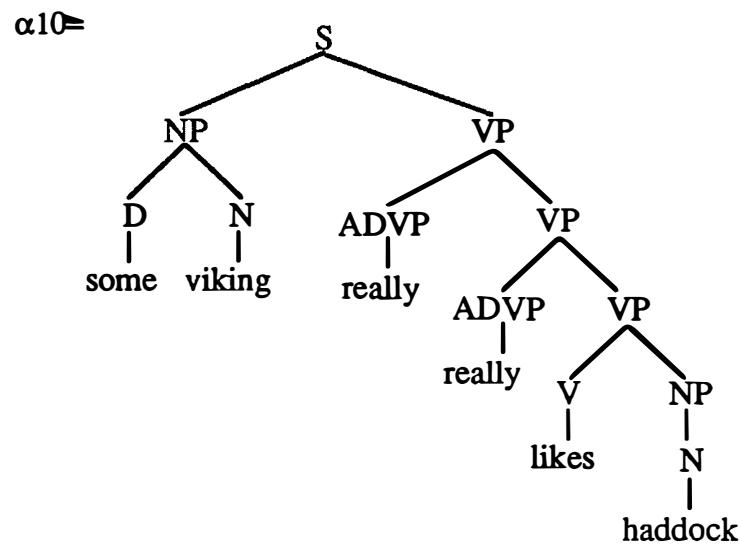


Figure 12 shows the derivation tree for α_{10} .

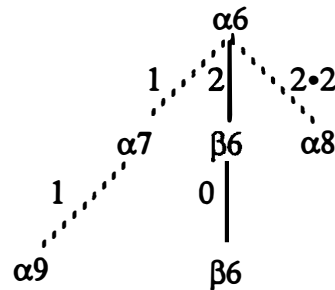


Figure 12: Derivation tree for α_{10}

Interpretation of derivation trees like Figure 12 is the same as in regular TAGs, except there are two operations to worry about instead of just the one. One interpretation of the above tree is that a derived form of α_7 was produced by substituting α_9 in the tree at the node of address 1 (D). This completed form of α_7 was substituted into α_6 at the node of address 1 (subject NP). α_8 was substituted into α_6 at the node of address $2 \bullet 2$ (object NP). β_6 was adjoined into the root of another β_6 , and this derived structure was then adjoined into α_6 at the node of address 2 (VP).

The order of the steps in the derivation is not specified and can vary, as long as each composition is an insertion into an elementary tree. Thus, α_8 could be substituted into α_6 before the completed α_7 , or vice-versa-- it makes no difference in the derivation. However, one could not substitute α_7 into α_6 and then substitute α_9 into α_7 , since α_7 would then be part of a derived structure, and TAG compositional operations cannot perform an insertion into a derived structure.

1.5. Multi-component Tree-Adjoining Grammars

Another TAG variant which is sometimes applied to natural language is multi-component TAG (MCTAG), which is distinguished by extended notions of elementary tree sets and compositional operations. This section provides a brief informal introduction to MCTAGs and then focuses on lexicalized multi-component TAGs.

1.5.1. Informal Description of Multi-component TAG

A multi-component tree-adjoining grammar (MCTAG) is a regular TAG in which the adjunction operation has been generalized so that sets of auxiliary trees can be adjoined to a given elementary tree (Joshi, 1987). Thus the auxiliary tree set of the grammar can contain not only individual auxiliary trees, but also sets of auxiliary trees which are inserted in a single operation.

A simple example for a formal language should point out the major features of MCTAG. Consider the grammar $G_3 = (I, A)$ depicted in Figure 13 (based on Joshi, 1987).

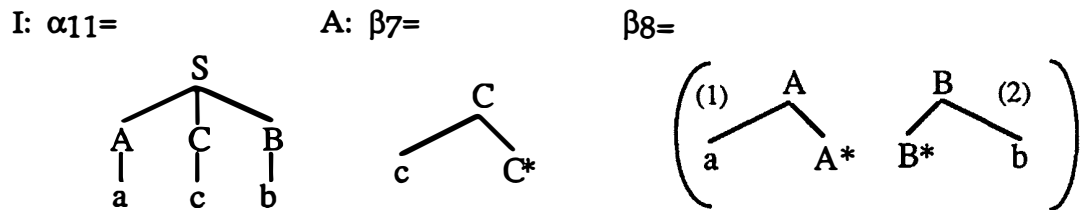
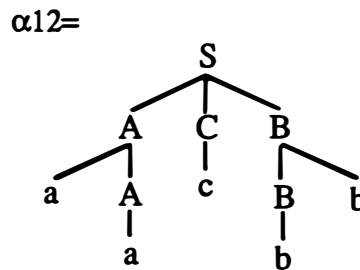


Figure 13: MCTAG G_3 for the language $L = \{w \mid w = a^n c + b^n, n \geq 1\}$

Note that β_8 is an auxiliary set containing two auxiliary trees, which we will refer to as $\beta_{8(1)}$ and $\beta_{8(2)}$. Adjunction of β_8 into α_{11} yields the tree α_{12} , below.



This tree is obtained by simultaneously adjoining $\beta_{8(1)}$ at address 1 of α_{11} and adjoining $\beta_{8(2)}$ at address 2 of α_{11} . In general, adjunction of an auxiliary set β into an elementary tree σ entails the simultaneous adjunction of all auxiliary trees in β into distinct nodes in σ . It turns out that the size of the auxiliary sets does not affect the generative capacity of the grammar as compared to regular TAGs (Joshi, 1987).

Although other formulations of MCTAG are possible (Schabes, 1991 pp58-9), we will restrict ourselves to consideration of grammars in which the elements of an auxiliary set are all adjoined into distinct nodes of the same elementary tree. This definition maintains both the weak and strong generative capacity of MCTAG at the same level as regular TAG. Other possible definitions increase the generative capacity of the formalism.

1.5.2. Example of Multi-component TAG Applied to English

Multi-component TAGs have been used by Kroch (1987) for analyzing natural language phenomena such as extraction from noun phrases. Figure 14 presents an initial tree and an auxiliary tree set based on his analysis.

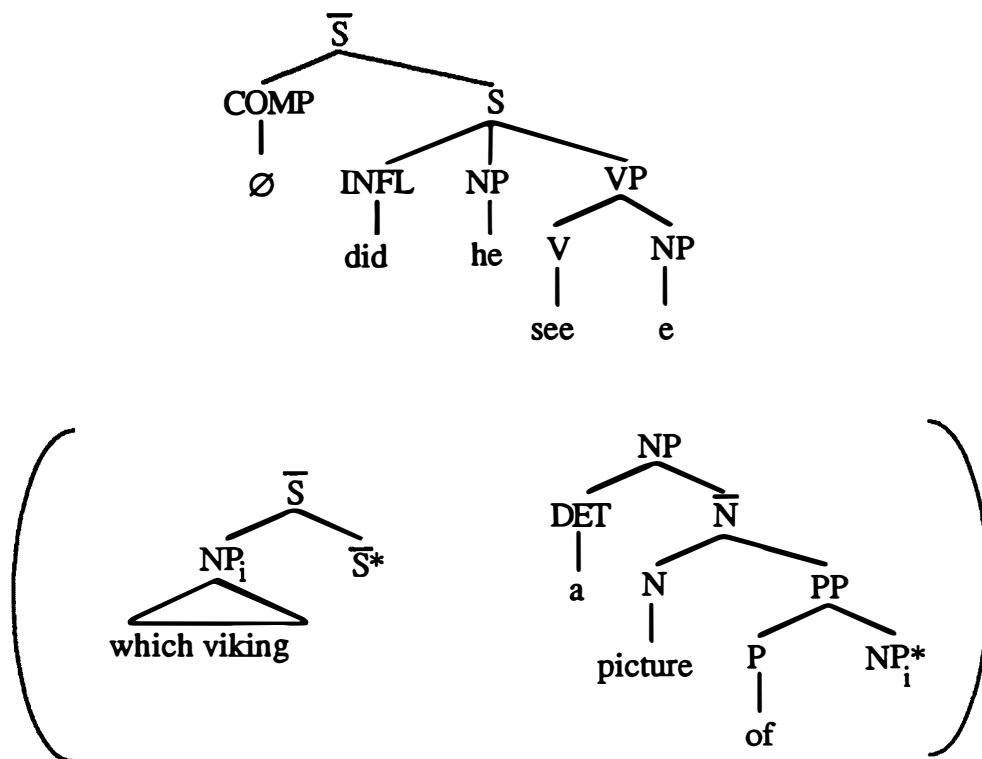
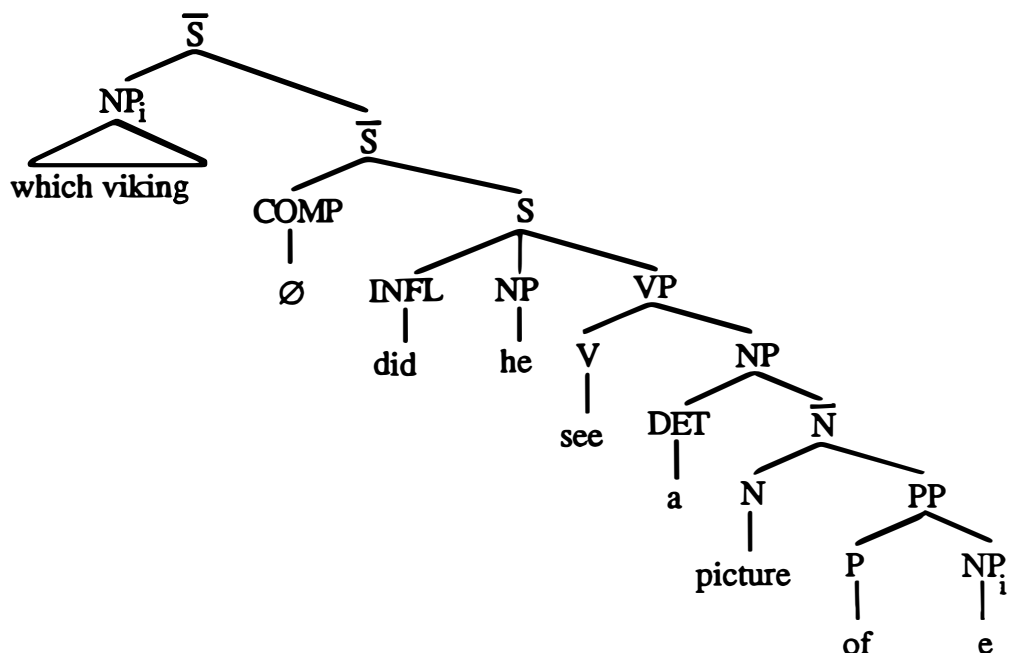


Figure 14: Some trees from a multi-component TAG for NP-extraction

Adjunction of the auxiliary pair into the initial tree generates the tree α_{13} , which corresponds to the sentence "Which Viking did he see a picture of?"

$\alpha_{13} =$



Of course, one could have adjoined the right auxiliary tree of the pair to the NP node dominating the terminal *he*, yielding the ungrammatical "Which Viking did he a picture of see." In practice, this overgeneration can be eliminated by placing a local constraint¹⁴ on adjoining on the NP node in question, but such concerns go beyond the pedagogical purpose of this example.

1.5.3. Lexicalized Multi-component TAG

A lexicalized multi-component TAG may be thought of as a regular lexicalized TAG $G = (\Sigma, NA, I, A, S)$ where I and A can contain elementary tree sets as well as individual elementary trees. Elementary tree sets in I can

¹⁴ TAGs with local constraints, although commonly encountered in the literature, will not be discussed in this paper. For an introduction to the formalism, see Joshi(1987).

contain only initial trees. Elementary tree sets in A must contain at least one auxiliary tree. An elementary tree set is one which contains only elementary trees. A derived tree set is one in which at least one element of the set has been the substrate of composition. The terminology can be somewhat confusing, since the elementary tree sets and their derived forms are independent notions from the tree set $T(G)$ generated by some grammar G .

Multi-component composition takes the following form:

All elements of a derived or elementary tree set are adjoined or substituted into distinct nodes in an elementary tree. This object tree can be an isolated tree or a tree in a tree set. Thus, derivation always proceeds with the adjunction/substitution of a tree set into an elementary tree, and as was noted above, this definition holds the generative power of multi-component lexicalized grammar G to the level of regular TAGs (Schabes, 1991).

1.6. Synchronous Tree-Adjoining Grammars

Synchronous TAGs were introduced by Shieber and Schabes (1990) as a means of explicitly associating structures in one tree language with structures in another. In particular, synchronous TAGs are intended to be used in relating expressions in a natural language to their corresponding semantics in a logical form (LF) language.

The remainder of this section will parallel the development of Shieber and Schabes (1990). Synchronous TAGs will be informally introduced with a simple example, and the possible advantages of this formalism over the more standard approaches to natural language semantics will be discussed. An explanation of the applications of synchronous TAGs to issues of quantifier scoping will be given in section 1.7.

1.6.1. Informal Description of Synchronous TAGs

A synchronous TAG is defined so that associations between expressions in two languages are explicitly stated and maintained. Each of the languages in the relation is rendered in terms of the same base TAG formalism. Choice of the base formalism is free. Each element of the synchronous TAG is a pair consisting of one elementary tree or tree set (in the case of a multi-component TAG base) from each of the source languages. In addition, linking relations may be specified between nodes in the trees or tree sets in a pair. In general, these links connect a set of nodes in one tree set with a set of nodes in another. These links provide for the synchronous derivation of expressions in the source languages (detailed in section 1.6.2 below).

Figure 15 illustrates a sample synchronous TAG linking a fragment of English to its predicate-argument structure, which is expressed in a simple logical form language. The base formalism chosen for this example is lexicalized single-component TAG, which was characterized earlier in section 1.4. Thus, links in a given pair only connect a single node in one tree with a single node the second. These links are indicated by heavy black lines drawn between the two nodes in question. If these links are ignored, the projection of a pair onto its first component yields an elementary tree from a TAG for a fragment of English. Projection onto the second element of a pair yields an elementary tree from a TAG for a fragment of an LF language.¹⁵

¹⁵ The non-terminal nodes in the LF grammar are abbreviations for Formula, Term, and Relation (or function). The motivation for the choice of LF grammar, and specifics of the language it generates, are discussed in section 1.7.

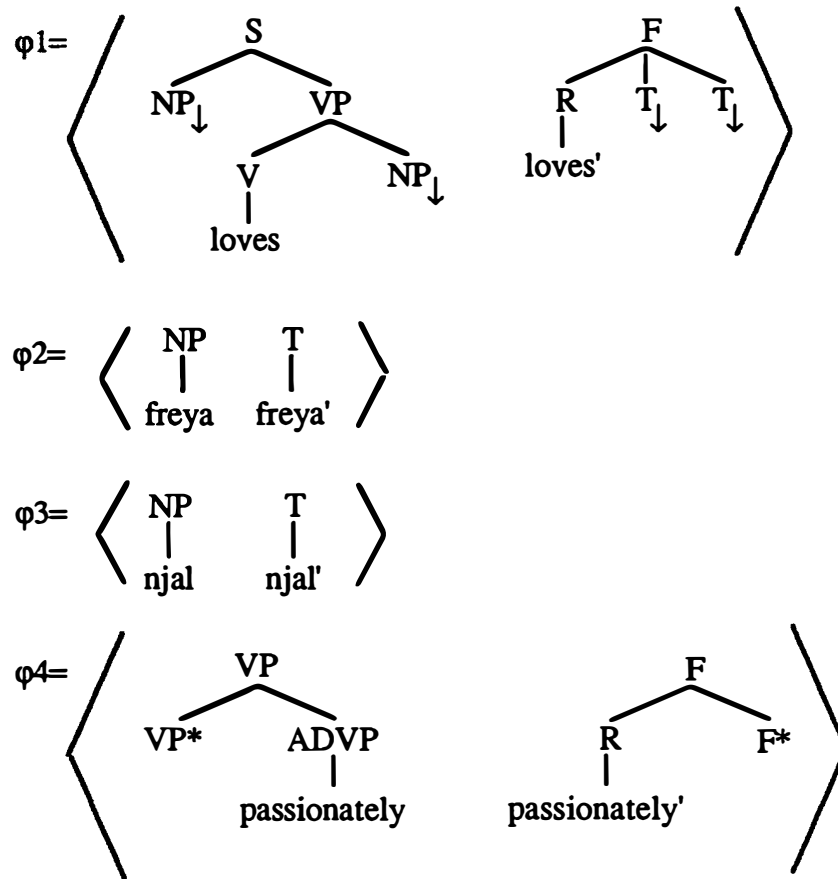


Figure 15: Tree pairs from a synchronous TAG for a fragment of English
(based on Shieber and Schabes, 1990)

1.6.2 Derivation in Synchronous TAGs

The derivation procedure for a synchronous TAG employs one elementary operation which is supervenient on the compositional operations in the base formalism. Shieber and Schabes (1990) characterize a derivation step from a pair of expressions¹⁶ $\langle \alpha_1, \alpha_2 \rangle$ as follows:

¹⁶ Shieber and Schabes (1990) stated this procedure in the context of an example using single-component lexicalized TAGs as a base formalism, so they only referred to pairs of trees. In a multi-component base, a pair could contain tree sets as elements, so I will use the term pair of

1. Nondeterministically choose a link in the pair connecting two node sets (say $n_1..n_p$ in α_1 and $m_1..m_q$ in α_2).
2. Nondeterministically choose a pair of expressions $\langle \beta_1, \beta_2 \rangle$ in the grammar.
3. Form the resultant pair $\langle \beta_1(\alpha_1, n_1..n_p), \beta_2(\alpha_2, m_1..m_q) \rangle$ where $\beta(\alpha, n_1..n_r)$ is the result of performing a primitive operation in the base formalism on some tree in α at node n_i using β_i for each i (e.g. adjoining or substituting β_i into some element of α at node n_i).¹⁷

A full derivation in a synchronous TAG then proceeds by choosing a pair of initial elements $\langle \alpha_1, \alpha_2 \rangle$ in the grammar and repeatedly applying the procedure above. In order for a derived pair to be in the tree-pair set $T(G)$ of a synchronous TAG G , projections of the pair onto both its left and right elements must be members of the tree sets $T(G_l)$ and $T(G_r)$ of their respective TAGs.

So, derivation in a synchronous TAG as defined in Shieber and Schabes (1990) is essentially a rewriting procedure¹⁸, in which a derived pair

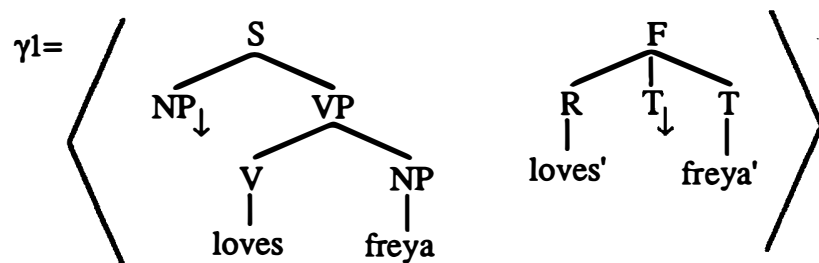
expressions for the general case, where the notion of an expression is defined by the base formalism.

¹⁷. This definition allows the operation at each node to differ. See section 1.7. for an example.

¹⁸. This rewriting procedure requires a modification in the definitions of adjunction and substitution as given above in sections 1.1 and 1.2. The definitions must be relaxed so that adjunction or substitution may occur into any tree, whereas before these operations could only be applied to elementary trees. The implications of this modification will be more fully discussed in chapter 2, but it should be noted here that the derivation in synchronous TAG is the inverse of the procedure in the TAG formalisms described in sections 1.1, 1.2, and 1.3. In those grammars, the direction of composition is that derived structures are inserted into elementary structures. In the synchronous TAG of Shieber and Schabes (1990), the direction of composition is that elementary structures are inserted into derived structures. Further discussion is deferred until chapter 2.

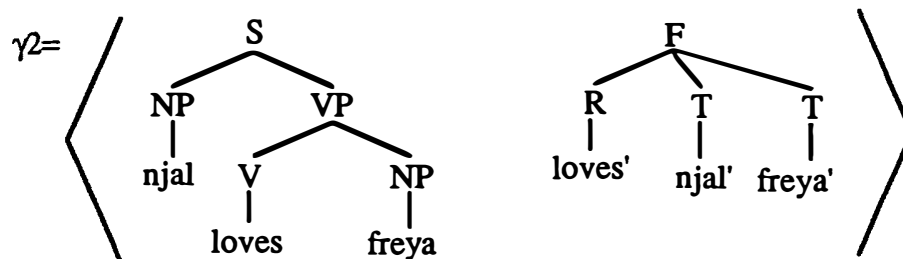
is built up by taking a pair of initial trees and repeatedly applying the above three steps. A problem associated with this definition of derivation is that it increases the generative power of the formalism beyond that of standard TAGs (Shieber, 1993). This topic is more fully addressed in chapter 2.

We can illustrate the derivational process using the sample synchronous TAG from Figure 15. Let us start with the tree pair ϕ_1 . First, we could choose the link from the object NP to T and the tree pair ϕ_2 , and apply ϕ_2 to the linked nodes. The substitution is synchronous, yielding the derived tree pair γ_1 :



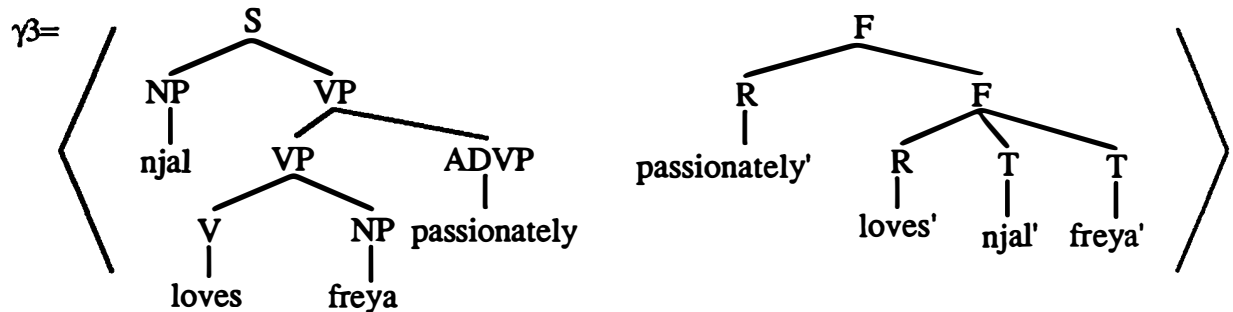
Note that the link acted upon has no counterpart in the derived tree pair. All other links are preserved by the derivation process.

If we then apply tree pair ϕ_3 to the remaining NP to T link, we get the following derived pair γ_2 :



This pair explicitly manifests the correspondence between the sentence "Njal loves Freya" and its logical form *loves'(*john'*, *freya'*)*.

We can continue the derivation using tree pair ϕ_4 , to generate the tree pair γ_3 .



This pair associates the meaning *passionately'(*loves'(*njal'*, *freya'*)** with the sentence "Njal loves Freya passionately."

1.6.3 Advantages of Synchronous TAGs

Synchronous TAGs offer several advantages over other, more conventional extensions to TAGs for the encoding of semantic information, such as semantic rules involving logical operations (as in Montague grammar or generalized phrase-structure grammar) or complex-feature-structure encodings (as in unification-based grammar formalisms) (Shieber and Schabes, 1990).

In particular, just as TAGs allow syntactic dependencies, such as subcategorization frames and agreement, to be localized in the elementary trees of the grammar, synchronous TAGs allow semantic dependencies to be localized in the logical forms of expressions in a natural language. These

dependencies, such as the long-distance referencing between a wh-expression and its associated bound variable or the signature requirements, such as argument type, of relation and function symbols, cannot be localized in the other approaches to semantics. The relevant information must instead be distributed throughout the derivation (Shieber and Schabes, 1990).

Thus, synchronous TAGs preserve the localized nature of dependencies which characterizes TAG analyses of syntax. This fact alone makes synchronous TAGs preferable to other mechanisms for adding semantics to a TAG framework for natural language syntax.

1.7. Application of Synchronous TAGs to Quantifier Scope

Shieber and Schabes (1990) proposed that synchronous TAGs can be applied to characterize quantifier scoping possibilities in natural language. As a base formalism, they employed multi-component lexicalized TAGs, which were discussed in section 1.5.3. above.

This section will characterize the source TAGs, syntactic and semantic, which were employed in Shieber and Schabes' example, and conclude with their synchronous TAG account of scope ambiguities in a two-quantifier sentence such as "Some Viking owns every longship."

1.7.1. The Syntactic Component

For the most part, the syntactic TAG of Shieber and Schabes (1990) consists of a lexicalized version of a fairly standard context-free grammar for English. As Schabes (1992?) proves on pages 23-5, any finitely-ambiguous context-free grammar can be lexicalized by some TAG. The base CFG

determines the linguistic constituencies manifested in the trees of the TAG.

Some rules of the base CFG are as follows:

$$S \rightarrow NP \ VP$$
$$NP \rightarrow D \ N$$
$$VP \rightarrow V \ NP \mid ADVP \ VP \mid VP \ ADVP$$

Although the syntactic TAG adequately accounts for the data that Shieber and Schabes (and I) consider, I do not make any claims for its absolute linguistic validity. The intention of the current work is not to find the correct TAG description for all of English, but rather to investigate the application of synchronous TAGs to quantifier scoping phenomena using a sample fragment of English. Since the heart of the synchronous grammar lies in the pairing and linking of trees from both a syntactic and an logical form TAG, the exact choice of syntactic description is be a primary concern. However, the constituent analyses provided by the CFG do not appear to be obviously controversial.

1.7.2 The Logical Form Component

For the logical form component of their synchronous TAG example, Shieber and Schabes (1990) employ a TAG lexicalization of a context-free grammar for a simple LF language. A central intuition captured by this language is that the propositional content of a sentence in a natural language consists of expressions restricting the range of quantified entities along with assertions about those entities. This notion can be formalized by placing the expressions relevant to the range of the quantified expression in a part of the expression called the *restriction*, and the assertions in a part called the *body* (Hobbs and Shieber, 1987).

The separate specification of range and scope seems to be necessary for a proper treatment of quantification in English. The work on generalized quantifiers by Cooper and Barwise (1981) indicates that all quantifiers other than those of first-order logic (thus, the vast majority of natural language quantifiers) require such a partition of the expression. In their view, a logical quantifier corresponds to an entire NP in the syntax, with the quantifier type being defined by the determiner of the noun¹⁹ and the body of the noun phrase comprising the restriction.

For example, consider the following sentence:

(4) Most Vikings drink.

A rough LF representation of the semantics of this sentence would be represented using four part quantifier structures as follows (using the notation of Moore, 1981):

$\text{most}(x, \text{viking}(x), \text{drink}(x))$

where $\text{viking}(x)$ is the restriction on the variable x and $\text{drink}(x)$ is the body.

This analysis is directly implemented in Shieber and Schabes' (1990) LF language. The base context-free grammar is $G = (\Sigma, V, R, F)$ where

$V = \{F, R, T, Q\}$

$R = \{ F \rightarrow R T T \mid R T \mid Q F F \}$

F = start symbol

Σ = the set of semantic values for terms in a fragment of English

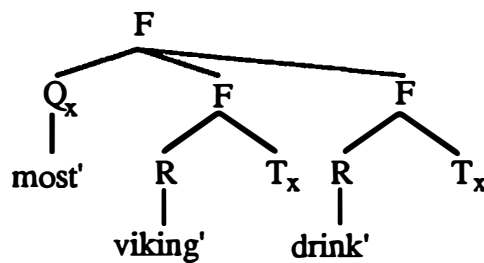
¹⁹ Barwise and Cooper (1981) assert that a noun phrase consisting only of a proper noun is also a quantified expression. In this paper the expression is notated as a variable bound by a quantifier corresponding to the proper noun. The restriction on the variable is implicit in the quantifier. So sentence a) below may be translated into the logic as something structurally similar to b) (following Barwise and Cooper (1981)):

a) John writes a thesis.

b) $(\text{john}(x), (\exists y, \text{thesis}(y), \text{writes}(x, y)))$

The rules of the grammar correspond to a two-place predicate (a relation between two terms), a one-place predicate (a function applied to a term), and a quantified expression (a quantifier, its restriction, and its body), respectively.

The LF TAG is a lexicalization of the above grammar, in which a quantified expression is specified in terms of a quantifier, restriction, and a scope. So, the projection of a derived pair corresponding to the sentence "Most Vikings drink" onto its LF component would be



Which is clearly the tree equivalent²⁰ of the flat LF structure given to the sentence under the four-part quantifier analysis. This analysis of quantifiers will be used throughout the remainder of the paper.

1.7.3 A Two-quantifier Example

Consider the synchronous TAG for a fragment of English in Figure 16 below (based on the example in Shieber and Schabes, 1990):

²⁰ The subscript x on certain nodes is a feature value on the nodes analogous to the variable bound by the quantifier in a flat LF expression. When there is more than one quantifier in the sentence, variable renaming occurs automatically so that each quantifier binds a distinct term type (Shieber and Schabes, 1990).

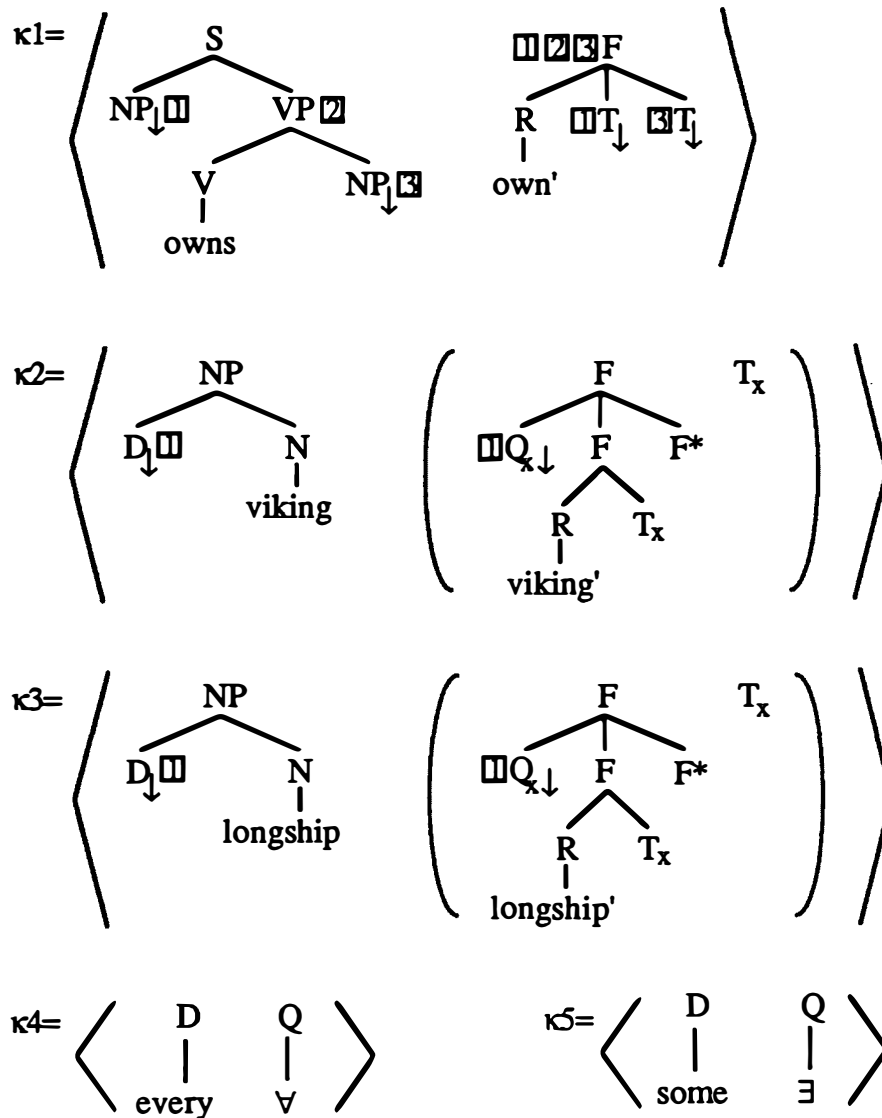


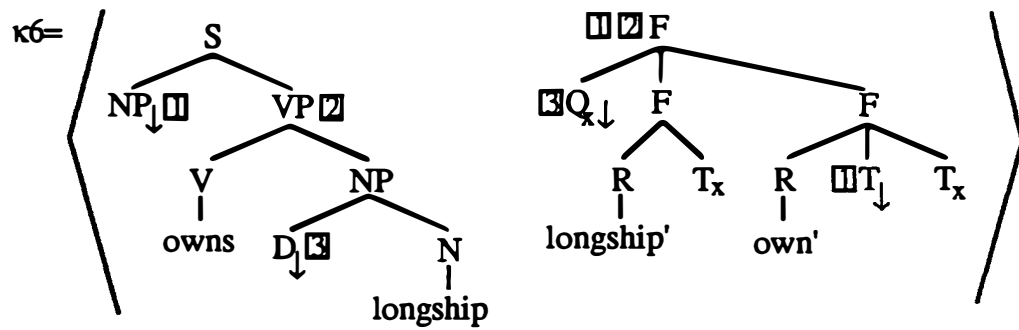
Figure 16: a synchronous TAG for analysis of quantifiers (based on Shieber and Schabes, 1990)

As has been stated before, the base formalism of this synchronous TAG is a lexicalized multi-component TAG. The primary use of tree sets occurs in the analysis of a quantified NP, which is linked both to a semantic formula representing the scope of the quantifier and a term, which is the position

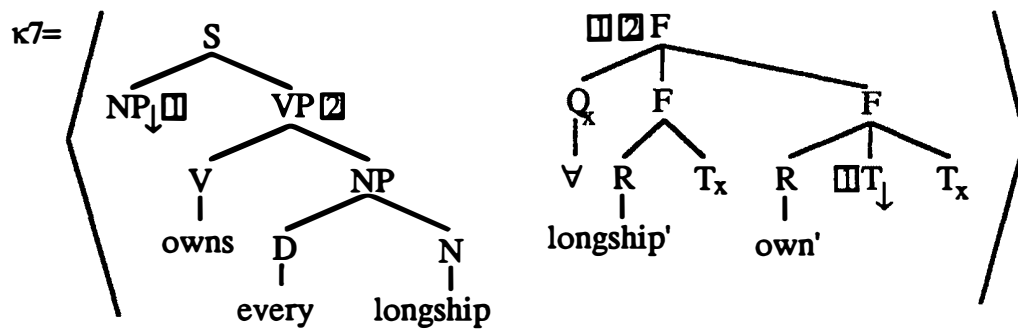
bound by the quantifier (Shieber and Schabes, 1990). Note that links are no longer explicitly drawn between the syntactic and LF trees in a pair. Instead, a coindexing notation is used so that there is no confusion between multi-component links and multiple separate links. Verb tense is ignored in the semantics, as is the case with all other grammars discussed in this paper.

To clarify the operation of this grammar, let us examine one possible derivation of the sentence "Some Viking owns every longship" with its associated semantics. We will begin with the initial pair κ_1 , choosing to act on index 3. Since this index links the object NP with both the F node and the second T node in the LF tree, the pair chosen to apply to the link must have tree sets of the correct sizes as its first and second components (1 and 2 in the current example). A pair which meets this requirement is κ_3 .

Now, a valid concern at this point is what happens when adjunction occurs into a node labeled with more than one link. If we apply κ_3 to link 3 in accordance with the procedure described in 1.6.2., where do links 1 and 2 end up in the LF tree-- at the root or at the foot of the adjoined tree? The convention established in Shieber and Schabes (1990) is that a node can be thought of as having a top and a bottom part, and that links impinging at the top of a node are associated with the root of the adjoined tree. Links impinging at the bottom of a node are associated with the foot node of the adjoined tree. In this paper, it is assumed that all links impinge at the tops of nodes, thus application of κ_3 at link 3 yields κ_6 :

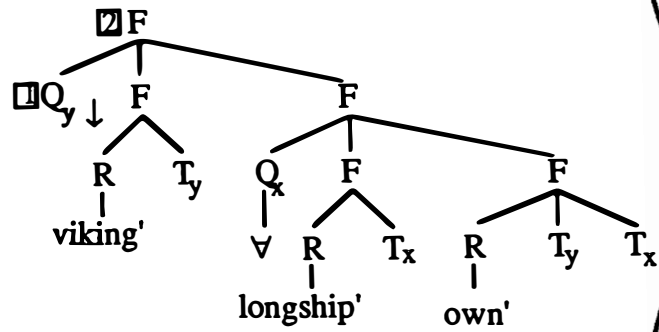
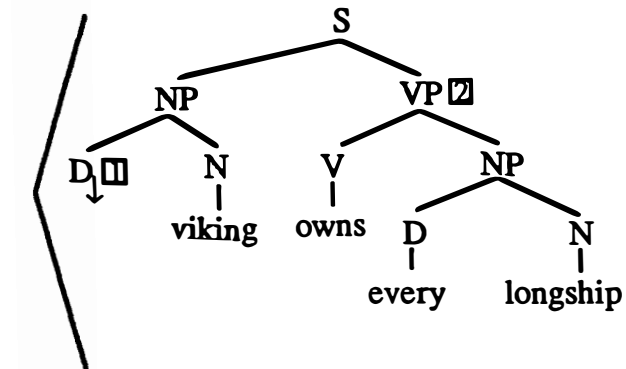


The quantifier can then be introduced by applying pair $\kappa 5$ to link 3, leading to

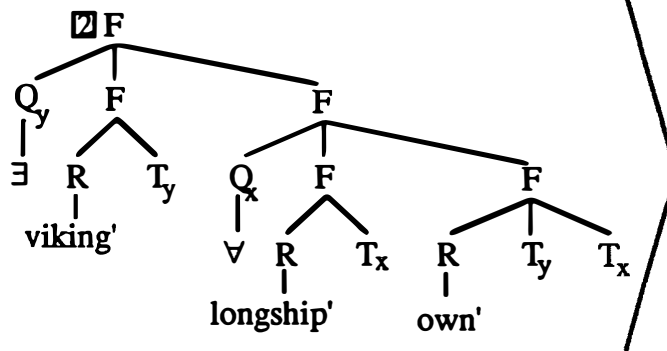
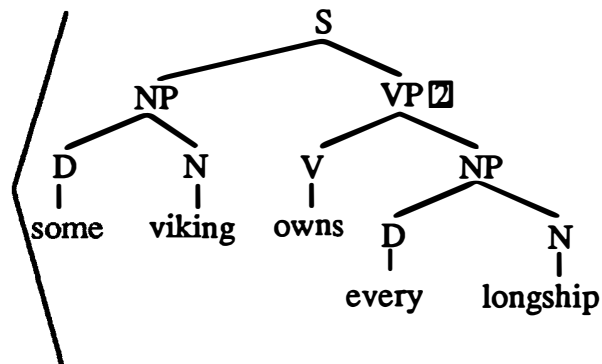


The last two steps in the derivation are illustrated below. The link being operated upon should be apparent from context.

k8=



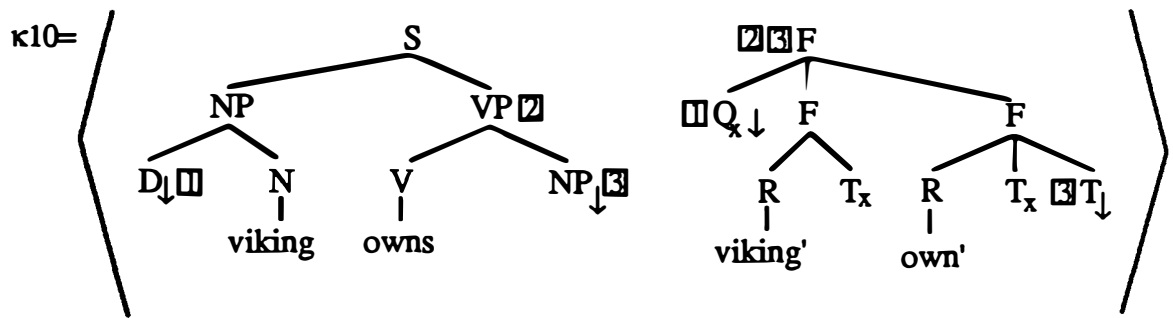
$\kappa_9 =$



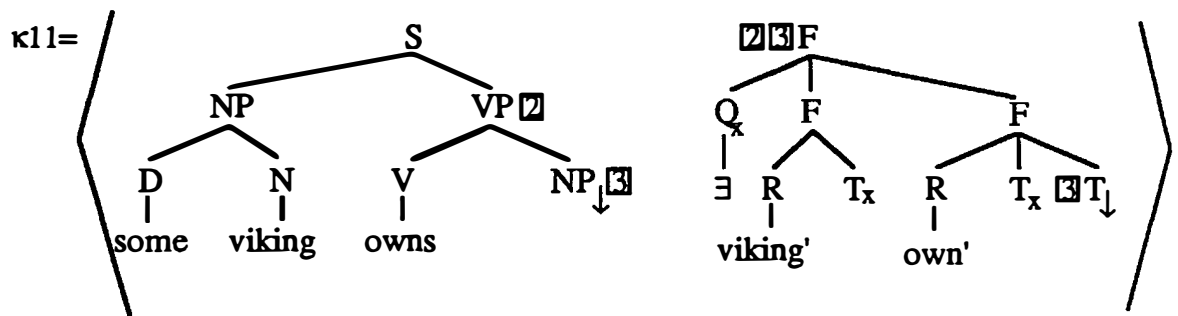
The final step of the derivation associates the sentence "Some Viking owns every longship." with the reading

$$\exists(y, \text{viking}(y), \forall(x, \text{longship}(x), \text{own}(y,x)))$$

If the order of the substitution of the NP's had been reversed, the other scoping order would have been generated, with no effect on the syntax. So, if we had begun by applying pair κ_2 to κ_1 at link 1, we would have derived κ_{10} .

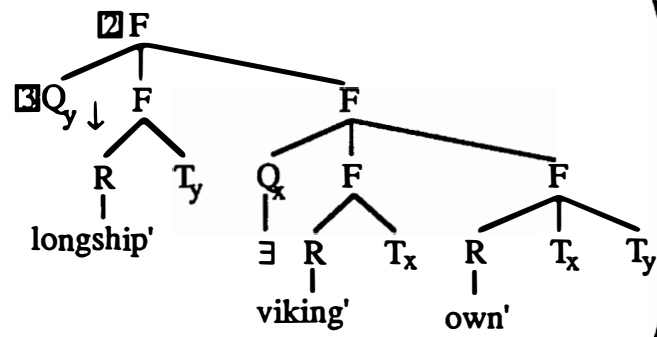
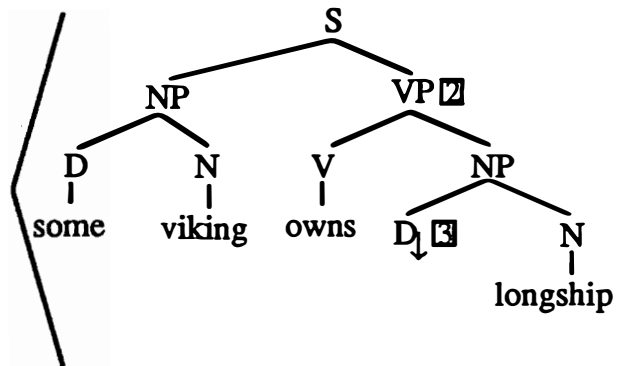


Applying pair κ_5 to link 1 introduces the desired quantifier, yielding κ_{11} .

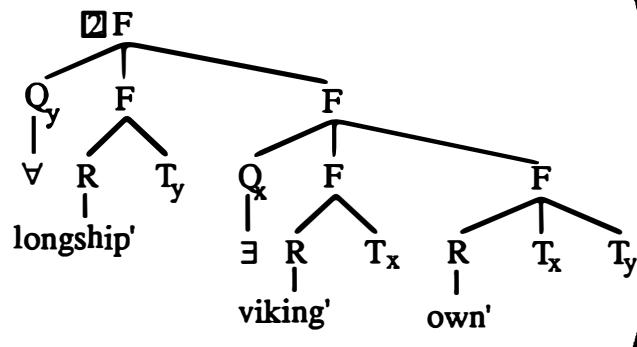
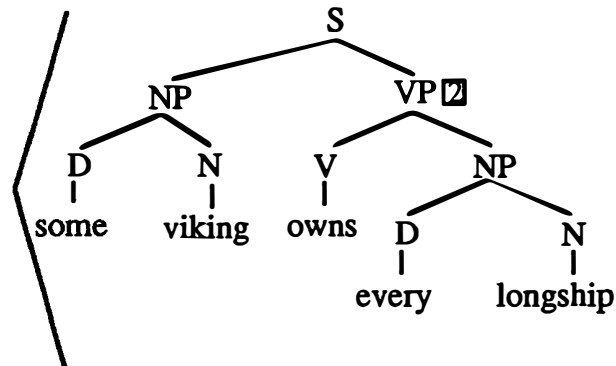


The derivation continues in a straightforward manner through the following two steps.

$\kappa_{12} =$



κ13=



The final step of this derivation, κ13, associates the sentence "Some Viking owns every longship" with its other possible reading, namely

$$\forall(y, \text{longship}(y), \exists(x, \text{viking}(x), \text{own}(x,y)))$$

Thus, the heart of the synchronous TAG approach to quantifier scoping ambiguity is that the order of the insertion of NP's in the derivation determines the relative order of the quantifiers in the semantics without affecting the derivation of the syntax. As we saw above, the NP inserted first has the narrowest scope, being outscoped by subsequent adjoined quantified NP's.

2. Quantifiers in Complex Noun Phrases

2.1 Overview

Hobbs and Shieber (1987) presented an algorithm to generate all logically possible scoped readings of a sentence of English, given an unscoped logical form written using notation for four-part quantifiers. The purpose of the investigation was not to generate a preferred reading, but to enumerate all of the logical possibilities, which might then be input into a heuristic engine that could pick the most likely candidate.

The approach in this chapter is in the same spirit as Hobbs and Shieber's work. The question is: can a synchronous TAG generate all of the logically possible²¹ readings of English sentences containing embedded quantifiers in complex NP's? Generation of preferred readings is not the goal of the enterprise.

Evaluating the formalism on the basis of logical possibility is a reasonable first step in a full account of quantifier scope relations, for it seems likely that the preference of certain readings as opposed to others is determined by the interaction of syntactic, discourse, and lexical factors, as proposed by Kuno (1991). Such extra parameters tend to muddy the waters when speaking of the linguistic possibility of readings, so it seems more circumspect to deal with the question of logical possibility first. Logical conditions thus set a baseline of accuracy for any proposed model, and thenceforth any mention of "possible scopings" shall be understood to refer to possibility in the logical sense.

²¹ Logical possibility is defined under a four-part analysis for quantifiers.

Initially, synchronous TAG analysis of quantifier scope ambiguity in English seems to be a rather straightforward exercise. The two-quantifier example in section 1.7. was quite naturally captured by the formalism. However, problems on two fronts quickly present themselves. First, the rewriting definition of synchronous TAG derivation is highly undesirable for a number of formal reasons, and so there is a necessity to redefine derivation in terms of a natural extension of standard TAG derivation (Shieber, 1992). Second, instances of quantifier embedding in complex NP's place certain restrictions on the number and type of quantifier scopings that are possible. It turns out that generating all of the proper scopings for these sentences under a non-rewriting definition of derivation is formally impossible. Thus, any TAG account of quantifier scoping involving embedded quantifiers is problematic in one way or the other.

In the subsequent section, quantifier phenomena involving complex NP's will be explored, ending with a discussion of the properties a synchronous TAG analysis must possess in order to account for the data. The next section shows that synchronous TAGs under the current definition of derivation can account adequately for the complex NP data. Then the problematic aspects of the current definition of derivation via rewriting in synchronous TAGs are discussed, and Shieber's (1992) solution is presented. We then proceed to show that no synchronous TAG under the new definition can fully account for the quantifier relations involving complex NP's. The chapter concludes with speculation as to whether there is middle ground between the two proposed definitions-- a definition which allows a complete account of the data but which maintains closer ties to standard TAG derivation.

2.2. Quantifier Embedding in Complex Noun Phrases

When dealing with ambiguous sentences containing more than one quantifier, such as

- (2) Some Viking owns every longship.

it is easy to assume that the possible scoped forms can be generated by simply taking all permutations of the quantifiers. Thus, a sentence containing n quantifiers should have $n!$ possible readings. This approach applied to (2) generates both of the possible readings, which were discussed in section 0.1.

This algorithm works fine for sentences containing only independent quantified expressions, such as (2) above and (4) below.

- (4) Every performer sang some opera for most critics.

Sentence (4) has six possible readings,²² corresponding to the permutations of its three quantifiers. Now, consider sentence (1), first presented in chapter 0., which contains the same three quantified NP's found in (4).

²² These readings can be shown to be distinct by the following exercise, suggested by Susumo Kuno. Consider the following sentence, which is syntactically equivalent to (4):

- (4') Ten performers sang three operas for two critics.

Given these numeric quantifiers, we can characterize all six scoped forms of (4') in terms of counts of how many performers, operas, and critics each maximally entails. Recall that the quantifier with the wider scoper is assigned a distributive meaning, so in the canonical ordering 10/3/2, the interpretation holds that there are 10 performers such that for each performer there are 3 operas such that for each opera there are two critics that she sang the opera for.:

	<u>Quantifier Order</u>	<u>Performers</u>	<u>Operas</u>	<u>Critics</u>
a.	10 3 2	10	30	60
b.	10 2 3	10	60	20
c.	3 10 2	30	3	60

- (1) Every performer of some opera pleased most critics.

Sentence (1) only has five of the six readings predicted by simple quantifier permutation.²³ The interpretation which (1) cannot have is the one where *most* outscopes *some*, but is outscoped by *every*. A little consideration should underscore the illegitimacy of this reading, for it asserts that for every performer there was a group of most critics that she pleased, and that for each critic she pleased there was some opera she was a performer of. The semantic intuitions of Hobbs and Shieber, as well as those of the present author, agree that sentence (1) cannot express the above meaning.

Hobbs and Shieber (1987) apply a four-part quantifier structure analysis of English in order to explain this missing interpretation of (1).²⁴ Under this

d.	3 2 10	60	3	6
e.	2 3 10	60	6	2
f.	2 10 3	20	60	2

²³. An exercise similar to the one performed in Footnote 18. will demonstrate to the reader that this assertion is in fact correct. Consider the following sentence, which is syntactically equivalent to (1):

- (1') Ten performers of three operas pleased two critics.

	<u>Quantifier Order</u>	<u>Performers</u>	<u>Operas</u>	<u>Critics</u>
a.	10(3) 2	10	30	20
b.	*10() 2 3	10	?	20
c.	3 10() 2	30	3	60
d.	3 2 10()	60	3	6
e.	2 3 10()	60	6	2
f.	2 10(3)	20	60	2

Where we run into trouble is the starred reading in (b). The stipulated order of quantifiers requires the following interpretation of the sentence: "There are 10 performers of some unspecified number of operas such that for each performer there are two critics such that for each critic there are three operas such that for each opera a performer pleased a critic." This is semantically ill-formed, since the actual number of operas is not specified until after a quantification involving this number has been made on the performers term. This point is more fully and formally discussed in the text.

²⁴. Four-part quantifiers and their notation were discussed in section 1.7.2. of the previous chapter.

model, the difference between sentences such as (2) and (4) and sentences such as (1) is that in (2) and (4), the quantified expressions are independent. That is, no quantified expression appears inside the restriction of another quantified expression. However, in a sentence such as (1), there is a quantified complex NP which has a quantified NP embedded in the complement of the head noun. Since the complement serves to specify and restrict the range of the term denoted by the head noun, the embedded quantifier appears in the restriction of the head noun quantifier in LF.

With this analysis in mind, Hobbs and Shieber then demonstrate that the sixth reading of (1) is impossible. The reading in question is the one where *most* outscopes *some* and *every* outscopes *most*. Thus, the universal has the widest scope of the three quantifiers. Put into the four-part quantifier notation discussed in 1.7.2., the LF form of the sentence must be

$$\text{all}(p, \text{performer}(p) \dots, \dots \text{pleased}(p, c))$$

We know that the *some* term restricts the range of variable p , so we put the existential in the restriction of the universal:

$$\text{all}(p, \text{performer}(p) \ \& \ \text{some}(o, \text{opera}(o) \ \& \ \text{of}(p, o)), \dots \text{pleased}(p, c))$$

The problem arises when we try to place the *most* quantified expression. It must bind the variable c in the body of the universal, but it must also outscope the existential in the restriction of the universal for the desired reading. The only way that *most* can meet both of these requirements is to outscope the universal, but this does not yield the desired reading either. Thus, this reading is impossible for sentence (1).

If we neglected the fact that the existential must occur in the restriction of the universal when the universal has wider scope, then the following LF expression could be generated for the reading in question:

(6) all(p, performer(p) & of(p,o), most(c, critic(c), some(o, opera(o),
please(p,c))))))

Notice that although the scope ordering is correct, the expression is ill-formed. The variable *o* occurs in the restriction of the universal, but its corresponding quantifier is necessarily in the body in order to establish the desired quantifier ordering. Thus, that instance of variable *o* is free, and the expression as a whole is not closed. Since expression (6) is ill-formed, the reading corresponding to (6) is impossible.

Thus, it is the complex NP construction which accounts for the missing reading of (1). In general, a quantifier from somewhere else in the sentence cannot interpose itself between the quantifier associated with a head noun and a quantifier associated with its complement when the head quantifier outscopes the complement quantifier (Hobbs and Shieber, 1987). Although we are focusing on PP complements as a handy example, the generalization holds for other head noun complements, such as relative clauses, as well.²⁵

2.2.1 Requirements for Analysis

Under the four-part quantifier analysis of English, any account of quantifier scope ambiguities involving complex NP's must express the fact

²⁵ It is possible to obtain readings of sentences containing relative clauses where a quantifier in the relative clause outscopes the quantifier of the head noun. For example, the sentence (5), suggested by Stuart Shieber,

(5) Every slush fund that each minister controlled was audited by some assistant.

has a strong reading where *each* outscopes *every*. This example is somewhat contrived, as it relies on the lexical properties of *each* to force the interpretation, but the mere possibility of the reading indicates that relative clauses are not islands which cannot be scoped out of. This suggests that relative clauses could be accounted for in a similar manner to prepositional phrases.

that the term associated with a head noun is restricted by the term associated with its complement. In order to ensure that all terms in the LF are properly bound, one of two arrangements must be the case. The quantifier associated with a head noun could outscope the quantifier associated with the head noun's complement, in which case the complement quantifier must be located within the restriction of the head noun quantifier in LF. For example, the canonical reading of sentence (1) reflects this state of affairs:

$\text{all}(p, \text{performer}(p) \ \& \ \text{some}(o, \text{opera}(o) \ \& \ \text{of}(p,o)), \text{most}(c, \text{critic}(c), \text{please}(p,c)))$

The alternative is for the quantifier associated with the head noun's complement to outscope the term of the head noun, in which case the head noun's restriction is still properly bound. This holds true, for example, in the $\forall/\exists/\text{Most}$ reading of (1):

$\text{some}(o, \text{opera}(o), \text{all}(p, \text{performer}(p) \ \& \ \text{of}(p,o), \text{most}(c, \text{critic}(c), \text{pleases}(p,c))))$

In this case, the restriction of the head noun contains the variable *o* corresponding to the term from the complement PP. This term is properly bound, since its corresponding quantifier outscores the expression associated with the head noun.

Thus, although no quantified expression from outside a complex NP can interpose itself between a head noun quantifier and a quantifier associated with the head noun's complement when the head noun outscores its complement, there is no such restriction when an NP in the complement outscores the head noun. The LF for the $\exists/\text{Most} \ / \forall$ reading of sentence (4) is perfectly well-formed under our analysis:

some(o, opera(o), most(c, critic(c), all(p, performer(p) & of (p,o), please(p,c))))

A complete analysis of scope phenomena involving complex NP's should generate all readings which meet either of the above conditions. In the case of sentence (4), which we will use as a test case, the number of readings generated should be five.

2.3. Synchronous TAG Account of Complex NP Scopings.

Figure 17 presents a synchronous TAG that will generate all five scoped forms of sentence (1), and no more. The tree pairs corresponding for the quantifiers themselves are not pictured, but they are like the ones employed in section 1.7.3.

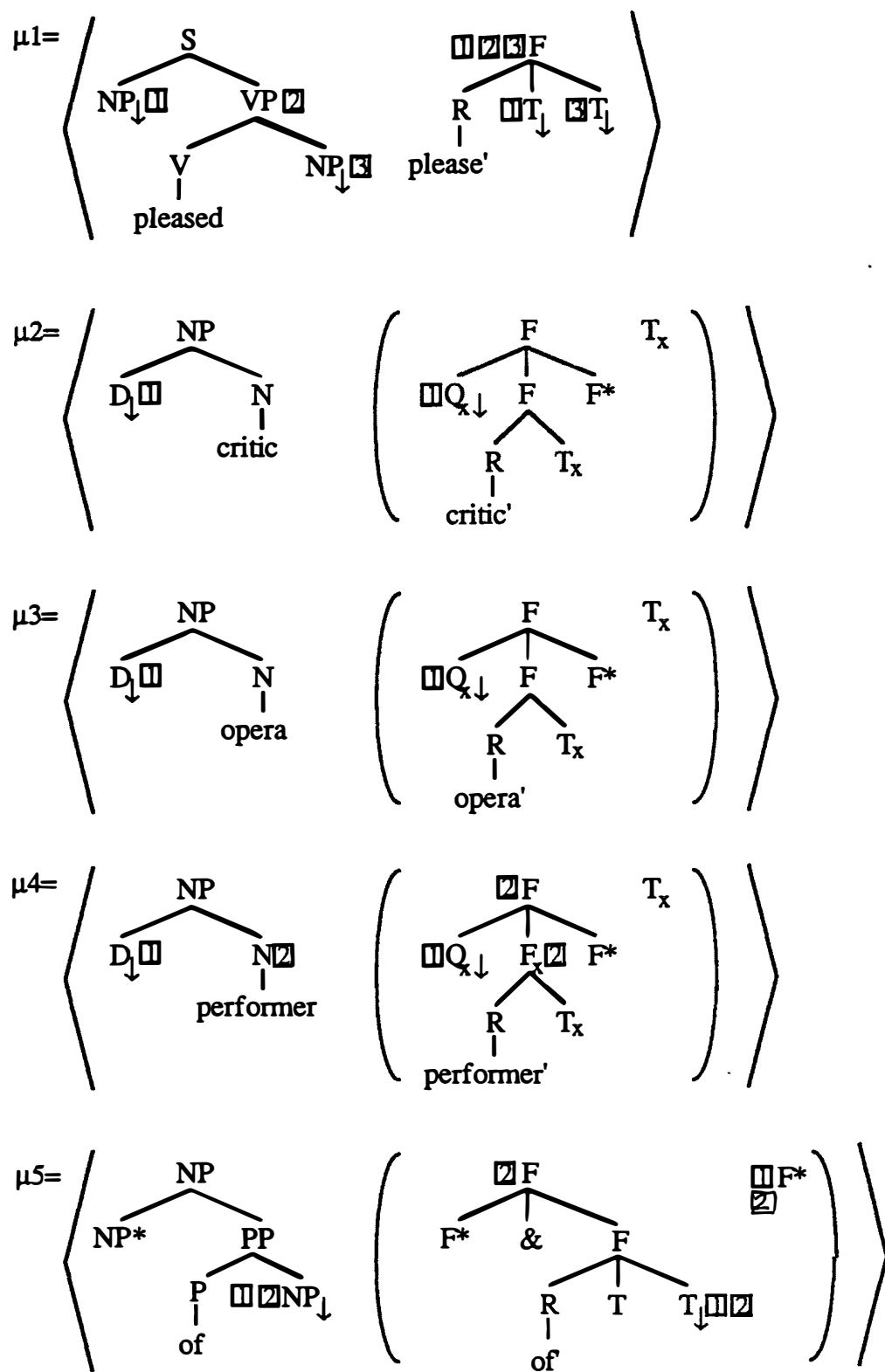


Figure 17: a synchronous TAG for sentence (1)

The key to this account is the implementation of the complex NP in pairs μ_4 and μ_5 . μ_4 is intended to represent an NP which can contain a complement. This difference is manifested as a second link, which joins the N node in the syntax with the topmost F and restriction F nodes in the semantics. The idea is that a nominal complement will adjoin into the N node in the syntax, and that the semantics of the complement will be in two parts, one adjoined into the root of the NP formula, and one adjoined into the restriction F. Thus, the quantified expression associated with the complement NP could either outscope the quantifier of the head noun, or be located in the restriction of the head noun, depending on which complement LF tree it is adjoined into.

This approach is implemented in the complement pair μ_5 as a syntactic tree associated with a semantic tree set by two links.²⁶ One aspect of this pair not noted in Figure 17 is a dominance restriction on the semantic tree set, such that when the tree set is adjoined into some elementary tree, the root of the right tree must dominate the root of the left tree. This restriction ensures that the left tree will always be adjoined at the restriction F in the head noun semantics, and the right stub will be adjoined at the root F of the head noun. This extension to the LF TAG is absolutely crucial to this analysis, and to my knowledge the formal consequences of such an extension have not been studied.

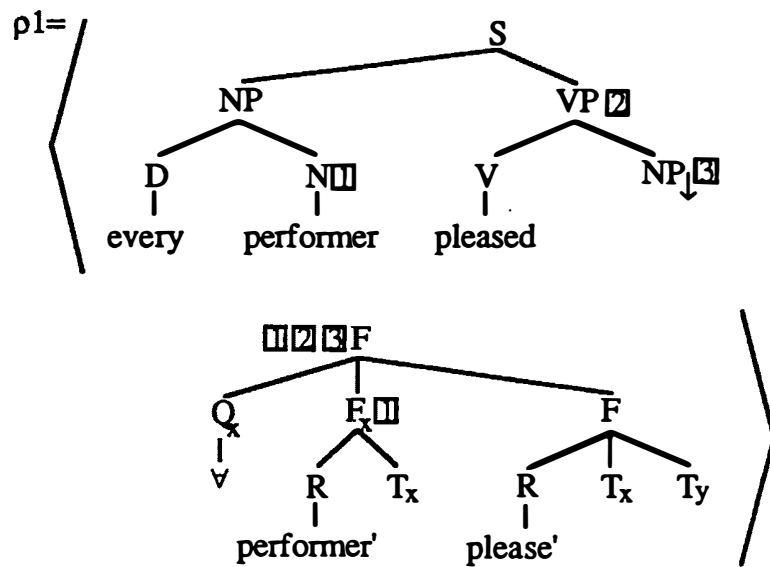
Notice also that the left tree of the LF set contains an unbound term T, which is not a substitution node. This generic term is used in conjunction with an additional feature specification (x) on the restriction F in the LF tree

²⁶ The use of a multi-component LF for the complement, and the indexing scheme in pair μ_5 were suggested by Stuart Shieber.

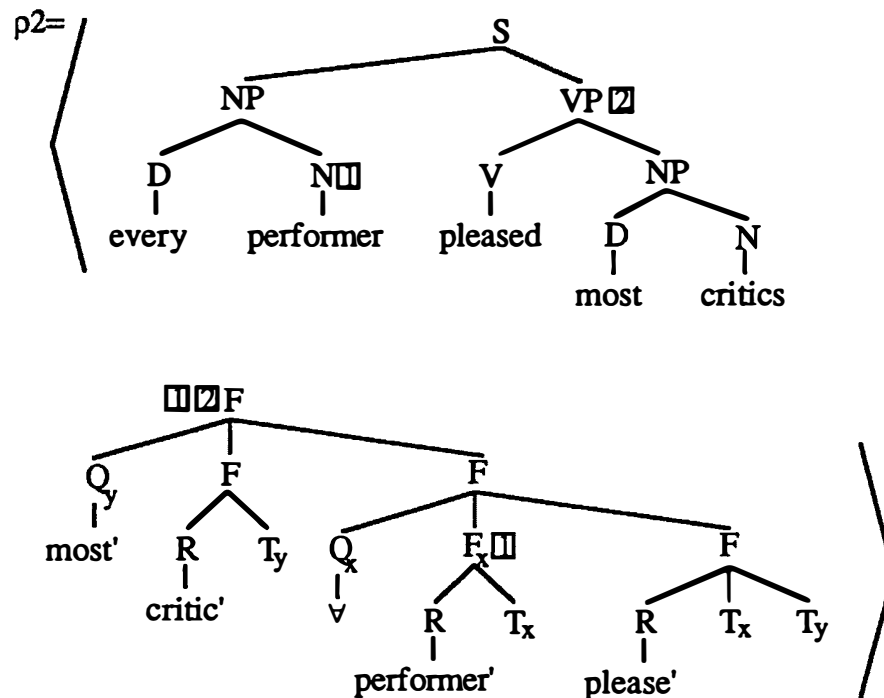
of the head noun, which is interpreted as explicitly specifying that the formula restricts the range of the term x bound by the quantifier. The idea is that when the left tree in the LF of the complement is adjoined into the restriction F of the head noun, this feature will be preserved, indicating that all unspecified terms in the formula are bound by the quantifier of x .

All of the mechanics described so far are designed for the sole purpose of allowing free variation in scoping between the quantifier of a head noun and the quantifier of its complement. Looking at the LF tree set of the complement, one sees two different links that may be acted upon to insert the NP object of the preposition. If link 2 is chosen, then the quantified LF tree of the NP is adjoined into the leftmost tree of the complement's semantic tree set, which is always adjoined into the restriction of the head noun. Thus, action at link 2 results in eventual adjunction of the quantifier of a complement NP into the restriction of the head noun NP. If link 1 is chosen, then the quantified LF tree of the NP is adjoined into the rightmost tree of the complement's semantics, which is always adjoined into the root of the formula corresponding to the head noun. Thus, action at link 1 yields a semantic tree where the quantifier associated with an NP embedded in a nominal complement outscopes the quantifier associated with the head noun.

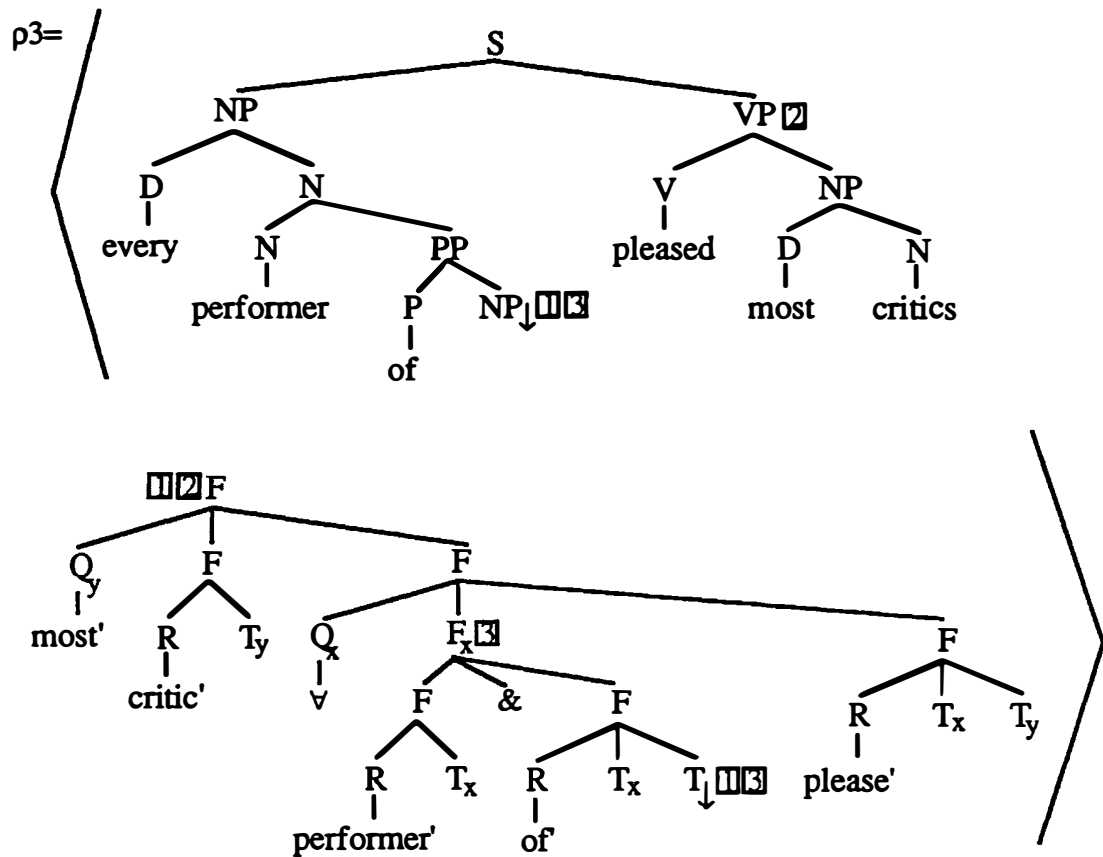
As an example of how the mechanism works, consider the derivation of the \exists /Most/ \forall reading of sentence (1), where *some* outscopes *most* outscopes *every*. In the interest of clarity, we will not be using the pairs as they appear in Figure 17, but rather derived pairs which already have the appropriate quantifiers inserted. Starting with pair μ_1 , we first apply pair μ_4 to link 1, yielding p_1 .



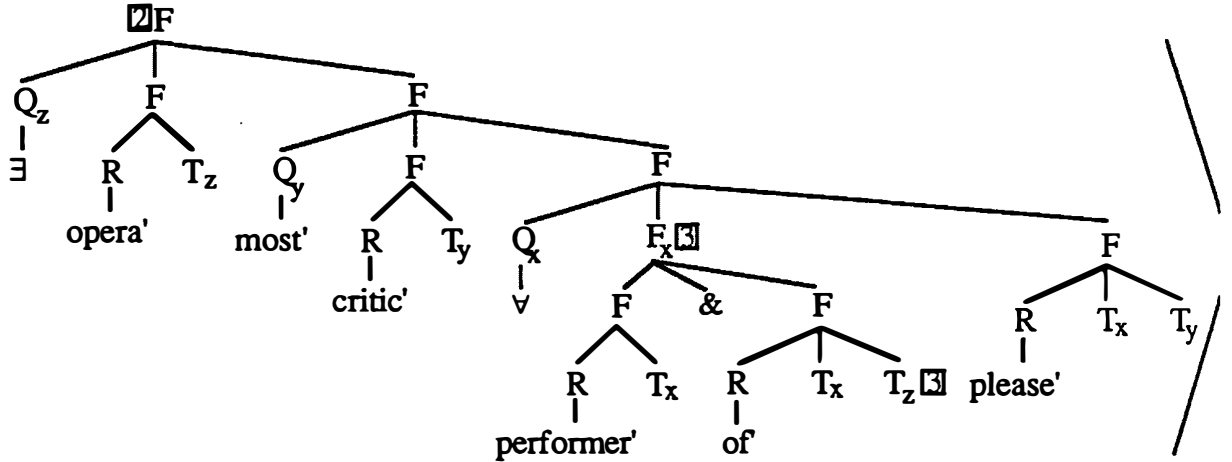
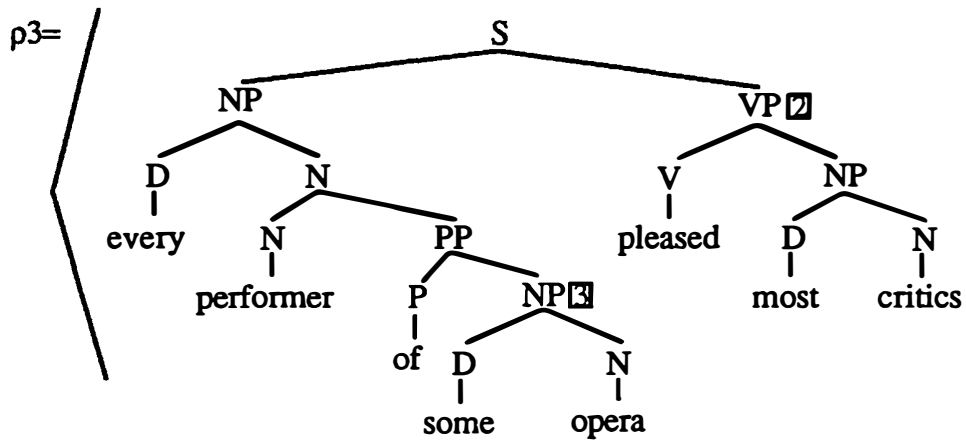
Now we choose link 3, and apply pair μ_2 , yielding ρ_2 :



Now we apply pair μ_5 at link 1.



At the last step of this derivation, we have a choice. We can apply the pair μ_3 at either link 1 or link 3. If we choose link 3, then the quantifier \exists will end up in the restriction of Q_x . We want the reading where \exists has the widest scope, so we choose to apply μ_3 at link 1, yielding the fully derived form ρ_4 .



Although the synchronous TAG in Figure 17 does generate the correct readings for sentence (1), there are certain aspects of the approach which are less than ideal. In p3 above, note that there are two links left in the tree after all derivation has been completed. Link 2 is the associational link between the syntactic structure as a whole and its semantic interpretation, as was indicated in section 1.6.2. However, link 3 is an artifact of the mechanism that allowed the quantified term embedded in the complement of a noun to optionally outscope the quantified term associated with the head noun. Perhaps it is too strong to require that all links present at the end of a

derivation are semantically meaningful, but at the least it seems that the links should be valid jumping-off points for further derivation. Such a derivation using link 2 was seen in section 1.6.2., involving the composition of an adverb modifying the VP of the sentence.

Link 3 above does not seem to be semantically meaningful, nor does there seem to be any construction which could employ the link in a derivation, as the pair currently stands. Thus, although the Figure 17 TAG formally accounts for the phenomenon, the analysis is not thoroughly satisfactory.

2.4. Revision of Synchronous TAG Derivation

Shieber (1992) points out that there is a major problem with the original definition of derivation in synchronous TAGs which was presented in section 1.6.2. Under this definition, henceforth referred to as the rewriting definition, synchronization of two TAGs results in an increase of the weak-generative capacity of the formalism such that the projection of string pairs onto a single component may be a non-tree-adjoining language. This can occur even though the strings of each component are specified with a TAG.

Shieber states this problem more precisely as follows: Recall that a synchronous TAG is defined in terms of two TAGs, which we will designate G_R and G_L . The synchronous TAG G itself may be thought of as a set of triples, $\{ \langle L_i, R_i, \cap_i \rangle \}$, where L_i is an elementary tree of G_L , R_i is an elementary tree of G_R , and \cap_i is the linking relation between addresses in L_i and R_i . Grammar G thus defines a language of pairs $L(G) = \{ \langle l_i, r_i \rangle \}$. Now, let x_L and x_R be the projections of a pair x onto its left and right components,

respectively. Shieber generalizes this notion to the first and second elements of a triple, and pointwise on sets of pairs and triples.

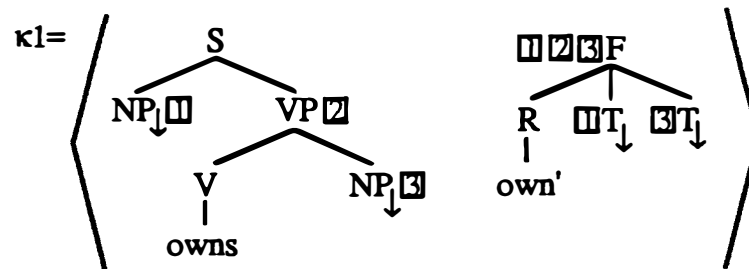
With this notation, one can clearly capture the problem with the weak-generative capacity of synchronous TAGs: For a synchronous TAG grammar G , $L(G)_L$ may not be a tree-adjoining language, even though $L(G_L)$ must be by definition.²⁷

Shieber's solution to the weak-generation problem is to abandon the rewriting approach to derivation altogether and instead formulate synchronous TAG derivation in terms of the standard definition of derivation for TAGs. Under this "natural" definition of derivation, a derivation in a synchronous TAG would be a pair of derivation trees $\langle D_L, D_R \rangle$, where D_L is a well-formed derivation tree with respect to G_L and D_R is a well-formed derivation tree with respect to G_R . The linking relations specified between the components of tree pairs in G would ensure that the two derivation trees are appropriately synchronized, such that D_L and D_R are isomorphic.

This definition restricts the weak-generative capacity of synchronous TAGs in the right way,²⁸ and naturally follows from the definition of the TAG formalism. However, it is problematic for the TAG analysis of quantifier scope, which requires multiple adjunctions at the same node. Consider the initial tree pair κ_1 from the example in section 1.7.3.

²⁷ For a formal language example of this problem, see Shieber (1992).

²⁸ See Shieber(1992) for a detailed explanation of this point.



In the LF component of the pair, the formulas for the quantified NP's of both terms must be adjoined at the root of the predicate formula when the NP's are substituted into different nodes in the syntactic tree. The standard definition of derivation requires that adjunctions must occur into distinct nodes in an elementary tree. Thus, there is no well-formed derivation of a quantified sentence using the above analysis of logical structure and the natural definition of derivation.²⁹

Shieber handles this difficulty by appealing to an extended notion of TAG derivation, which was independently motivated and discussed in Schabes and Shieber (1992). This approach divides the class of auxiliary trees in a TAG into two groups, predicative trees and modifier trees. Whereas in the standard definition, a derivation tree is well-formed if there is no more than one auxiliary tree adjoined into a given node in a given elementary tree, in the extended definition, the derivation tree is well-formed if there is no more than one predicative tree adjoined into a given node in a given elementary tree. Thus, multiple adjunctions of modifier trees are allowed into the same node of the same tree. Moreover, all allowed adjunctions into the same node of the same tree are ordered with relative to one another, so the derived tree is exactly specified. Figure 17 presents a diagram from

²⁹ It is for this reason that the rewriting formulation of synchronous TAG derivation was proposed in the first place (Shieber, 1992).

Schabes and Shieber (1992), which illustrates the interpretation of a derivation tree with multiple adjunctions at a single node.

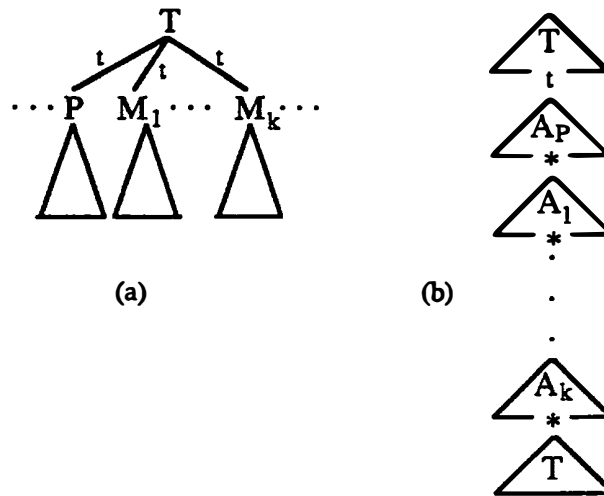


Figure 17: Interpretation of derivations with multiple adjunctions at a single node (Schabes and Shieber, 1992)

The (a) side of Figure 17 depicts a situation in which one predicative node (P) and k modifier trees ($M_1..M_k$) have been adjoined into tree T at node t . The (b) side of the figure shows what the derived tree looks like after such an adjunction. The left-to-right ordering of the auxiliary trees in the derivation tree is recapitulated in the top-to-bottom stacking of the auxiliary trees in the derived tree.

If the natural definition of synchronous TAG derivation were modified to include the extended notion of derivation above, then the synchronous TAG analysis of quantifier scope ambiguity given in section 1.7.3. above is possible. We simply designate the quantified formulas associated with complex NP's as modifier trees, which can be simultaneously adjoined into the the formula for the predicate.

At this stage, it seems that this revised natural definition of derivation is the correct characterization of synchronous TAGs. Weak-generative capacity of the formalism is restricted to only the tree-adjoining languages, and analysis of quantifier scoping ambiguity seems possible.

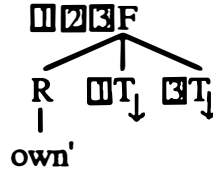
2.5. Inadequacy of the Revised Definition

The extended natural definition of synchronous TAG derivation presented in Shieber (1992) seemed to solve the generational problems associated with synchronous TAGs without compromising any flexibility needed for analysis of natural language quantifiers. However, the analysis of quantified complex NP's indicates that the extended standard definition is still too restrictive in terms of the analyses it permits. Recall our example sentence (1):

- (1) Every performer of some opera pleased most critics.

In section 2.1., we showed that sentence (1) has only five possible readings. It turns out that a synchronous TAG analysis using the extended natural definition of derivation can generate only four readings. The missing reading is the one in which *some* outscopes *most* which outscopes *all*, which was shown to have a well-formed LF representation in section 2.1. and which we derived under the rewriting definition in section 2.2.

This fact follows very simply from the examination of the derivation tree for the logical form expression corresponding to (4). If we assume an analysis where the left component of the initial pair for the sentence is something like the following:



then the derivation tree for the LF could take one of two forms. The quantifier associated with the first term could be ordered before the quantifier associated with the second, or vice-versa, yielding the two structures in Figure 18.

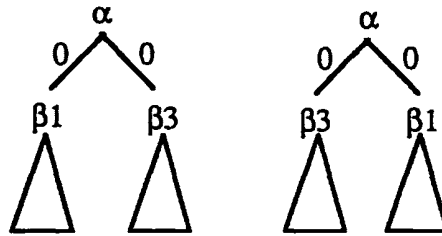


Figure 18: Partial derivational trees corresponding to sentence (4)
(substitutions omitted)

The key observation to make is that these derivation trees must be well-formed with regard to extended TAG derivation. Thus, the quantified expression associated with the first term, which corresponds to the complex NP *every performer of some opera*, must be fully derived by the time it is adjoined into the root of the predicate tree. This condition accounts for the generation of only four orderings. Within the expression associated with the complex NP, *every* can outscope *some* or vice-versa, depending on a choice made during derivation. Once expression for the first argument is derived, it can be adjoined into the root of the predicate LF with the expression for the

second argument in either order, yielding four distinct scoped forms for the sentence. These readings may be written schematically as

$$[\text{every} \Leftrightarrow \text{some}] \Leftrightarrow \text{most}$$

where the double-headed arrow between two terms indicates that the ordering of the terms can be taken either way.

The fifth reading is impossible because it requires the adjunction of the quantified expression embedded within the expression of the complex NP into the root of the predicate as well. This was possible under the rewriting definition of derivation, as was shown in section 2.3. In that derivation, we first derived the sentence "Every performer pleased most critics" and then rewrote the sentence to add the complement PP, allowing the quantifier of the complement to be adjoined last, and therefore have widest scope.

In general, a synchronous TAG defined under the extended natural definition of derivation will not generate any scoped readings in which a quantified expression from elsewhere in the sentence interposes itself between a quantified expression for a head noun and a quantified expression for its complement, no matter what ordering holds between the two quantified expressions. Thus, under this definition, no adequate synchronous TAG account exists for the scoped forms of sentences containing complex NPs.

2.6. Summary

Sentences containing complex NPs pose a thorny problem for synchronous TAG accounts of quantifier scope ambiguities. The scoped

forms of such sentences can be accounted for, but only under the original rewriting definition of derivation, which Shieber(1992) demonstrates to be formally undesirable. The extended natural definition of derivation which he proposed as a replacement for the original definition does not permit a complete account of the phenomena-- synchronous TAGs using this derivation protocol will always undergenerate.

It would be nice if there were a definition of derivation flexible enough to fully account for the data while still maintaining the weak-generative capacity of the grammar at the level of the tree-adjoining languages. Unfortunately, the reading missing from the extended normal account relies heavily on the flat rewriting capabilities of the original definition for its derivation. In the semantic component of the grammar, the process is one of adjoining a partially derived quantifier tree into the sentential semantics as the first step, then adjoining another quantifier, and finally completing the derivation of the first tree adjoined. So far, I have not found a way to obtain this fifth reading by any means except the rewriting definition. Unfortunately, the question must therefore be deferred for future research.

3. Scoped Forms of Central Noun Phrases

3.1. Overview

We will now turn our attention to another scoping phenomenon in English, which was characterized by Witten (1972). His investigation examined the ambiguity of sentences such as (7).

(7) Gunnar claimed that Helgi owns no more than one longship.³⁰

Ambiguity arises because the final quantified NP can be interpreted as either scoping within the embedded sentence or as having wide scope over the entire sentence. Thus, (7) could express the thought that Gunnar claimed that there is no more than one longship that Helgi owns, or that there is no more than one longship that Gunnar claimed Helgi owns. As Witten points out, the first interpretation would be exclusively correct if Gunnar said "Helgi owns no more than one longship," and then said "Both the longships in port - the *Vulture* and the *Scramasax* -- are owned by Helgi." In this scenario, Gunnar has contradicted himself, and sentence (7) can only have the interpretation that Gunnar's claim was that Helgi owned no more than one longship. The second interpretation is blocked since Gunnar also claimed Helgi owns two ships, namely the *Vulture* and the *Scramasax*.

If Gunnar had said "Helgi owns the longship *Vulture*" and nothing more, then the interpretation blocked above is exclusively true. It is not the case that Gunnar claimed "there is no more than one boat that Helgi owns,"

³⁰ This example and the following discussion are adapted from Witten (1972).

but it is true that there is no more than one boat that Gunnar claimed Helgi owns, for he only claimed that Helgi owns the *Vulture*.

The reading in which the final NP scopes the entire sentence is termed the central reading by Witten (as opposed to the preferred or normal reading), and the NP in this interpretation is referred to as a central NP. By and large, the central reading is not preferred and can be quite obscure, but it is a possible reading of the sentence such as (7), which can be emphasized using appropriate context.

Just as chapter 2 addressed the question as to whether synchronous TAGs could generate the correct scoped readings for sentences containing complex NP's, this chapter investigates whether a synchronous TAG account can correctly generate the scoped forms of sentences. like (7) above, which can be interpreted centrally.

The next section introduces centrality as characterized by Witten (1972), including some discussion of his account and the data it excludes. In addition, centrality is examined in the context of examples which are more general than those which Witten considers, pointing out the possibility that Witten's account of the phenomenon is oversimplified. A base synchronous TAG account of centrality is then presented, including a discussion of how the account can be modified to suit the exact definition of centrality employed. The chapter concludes with a general summation of the topics discussed that touches on the possible implications of the centrality phenomenon for the effort to develop a definition of synchronous TAG derivation which is formally constrained but flexible enough to account for natural language phenomena.

3.2. Central Noun Phrases

In this section, centrality and central noun phrases are informally introduced, following Witten(1972). Then, the concept of centrality is examined more closely, and Witten's characterization of the phenomenon is generalized. In the course of this discussion, a question about the extent of normal/central ambiguity is posed, which has implications for a synchronous TAG account of the phenomenon.

3.2.1. Informal Introduction to Centrality

Witten (1972) presents a purely syntactic account of a scoping phenomenon, called centrality, which is observed in certain sentences containing quantified NPs. In particular, sentences which have main verbs taking sentential or infinitival complements can exhibit central readings. For example, all of the following sentences are ambiguous between central and normal readings:

- (8) Njal wants to buy two sheep.
- (9) Thrain ordered Kari to prepare three feasts.
- (10) Bjorn insisted that Freya saw no one.
- (11) It was alleged that Kol had betrayed at least seven Vikings.

In each sentence above, the final quantified noun phrase can be interpreted as scoping within the verbal complement (the normal reading) or as scoping over the entire sentence (the central reading). In the central reading of a sentence, the NP scoping the entire sentence is referred to as a central NP.

For example, sentence (8) can be interpreted in two ways: In the normal reading, what Njal wants is to buy two sheep-- the sheep can be any sheep, they are not specified. In the central reading, there are a specific two sheep that Njal wants to buy. These two readings can be expressed in four-part quantifier notation, if we assume that a verb such as *want* is a two-place relation between a term and a formula. The readings are rendered in (8').

(8') normal: (njal{x}, want(x, (2y, sheep(y), buy(x,y))))

central: (2y, sheep(y), (njal{x}, want(x, (buy (x,y)))))

Witten (1972) employs question-and-answer dialogues to draw out the centralized readings, since they can be somewhat obscure. For example, the following context serves to increase the visibility of the central reading of (10).

(12) Who did Bjorn insist that Freya had seen?

He hinted that Freya had seen Hrut and Sigurd, but he insisted that she had seen no one.

Aside from an interpretation in which Bjorn has contradicted himself, hinting one thing and insisting another, the response in (12) has the central reading where there is no one who Bjorn insisted that Freya had seen.

Witten also notes that the centralized reading is actually preferred in certain contexts, such as (13)

(13) Ian says that he meant one thing-- but he really meant another.

Witten holds that the default reading of (13) is the central reading "There is one thing that Ian says that he meant-- but he really meant another," rather than the normal reading "Ian says that there is one thing that he meant-- but he really meant another."

In the case of sentences containing sentential complements to the main verb, such as (10) and (11) above, an NP can be central only if it is located at the end of the sentence. This is Witten's so-called "Caboose Constraint." Contrast the interpretation of (10) above with (14), which reverses the order of the NP's in the complement sentence.

(14) Bjorn insisted that no one saw Freya.

Although the NP *no one* could be interpreted as central in (10), it cannot be in (14) since (14) is unambiguous. The only reading possible for (14) is the normal reading where the proposition that Bjorn insisted upon was that no one saw Freya. Thus, only the last NP in the complement sentence has the opportunity to scope out of the embedded S.

Witten further strengthens this restriction by proposing that an NP can be interpreted as central only if it is the very last phrase in the sentence. He bases this proposal on evidence that a prepositional phrase occurring after the last noun phrase in the complement blocks a centralized reading of the sentence. His examples³¹ are as follows (the parenthetical expression in (15) is original, the bracketed expression in (16) was added by the present author):

(15) Bill says that he meant one thing (but he really meant another).

(16) Bill says that he meant one thing in his speech [but he really meant

³¹sentences (47) and (48) in the original text

another].

Sentence (15) is equivalent to sentence (13) above, which was stated to have a predominant centralized reading. Witten seems to claim³² that the centralized reading of (16) is impossible, and concludes on the basis of this evidence that a central NP must come at the very end of its clause.

I am not convinced by this evidence, for if the cuing material is provided in (16) as it is in (15), I can obtain a centralized reading of (16). A paraphrase of this reading is "There is one thing that Bill says that he meant in his speech-- but he really meant another thing." I will admit that the central reading of (16) is more difficult to obtain than that of (15), but based on my own intuitions, I see no indications that the central reading of (16) is forbidden or impossible in the same way that the central reading of *no one* in (14) is impossible.

Further evidence that Witten's Caboose Constraint may be too strong comes from sentences which contain infinitival complements. Witten excluded these sentences from consideration in the formulation of his definition of centrality because they posed so many counterexamples to his claims, particularly the Caboose Constraint. For example, sentence (17)³³ has a reading where *one baloon* is central.

(17) Sam wants to balance one balloon on his nose.

³² I say "seems to claim" since his language is unclear-- he first states that (16), presumably with a centralized interpretation, is "poor," and then goes on to state that "if (16) is grammatical, it is grammatical on the normal reading" (Witten, 1972: IV-18). I take his meaning to be that the centralized reading of (16) is impossible.

³³Witten's sentence (56)

The centralized reading of (17) may be paraphrased as "There is one specific balloon that Sam wants to balance on his nose," in contrast to the normal reading "Sam wants to balance one balloon on his nose (as opposed to balancing two or three)." Again, the central reading is obscure, but not missing entirely.

However, on Witten's side are sentences such as (18)³⁴, where the central reading does appear to be missing because of a sentence-final prepositional phrase.

(17) Sam believes that Nina balanced one balloon on her nose.

A final answer to this question is beyond the scope of the current endeavour, since it involves very subtle judgements on rather obscure and/or impossible readings, which no doubt vary from speaker to speaker. What can be said with certainty is a minimum requirement for centrality, which is weaker than Witten's Caboose Constraint. In sentences consisting of a main clause and an embedded clause which is the complement of the main clause verb, an NP in the embedded clause may be central only if it is the final argument NP³⁵ in the clause. Thus, this formulation would allow the centralized readings of (16) and (17), while not allowing the centralized reading of (15).

This being said and done, we will henceforth restrict our attention to sentences which end with an argument NP of the embedded clause-- such as sentences (8)-(11). Besides being less problematic, these sentences constitute a base case for the centrality phenomenon which must be correctly captured in any analysis.

³⁴Witten's sentence (55)

³⁵ i.e. an NP which is an argument of the clausal verb, as opposed to an NP embedded in a prepositional phrase, for example.

3.2.2. Scoped Forms of Central Readings

In the last section, it was said that in a centralized reading of a sentence like (18), the central NP scopes the entire sentence. This is an accurate paraphrase of Witten's (1972) claim, and thus far has been accepted as a reasonable description of the phenomenon.

(18) Odin thinks that Thor ate six oxen.

However, if one moves beyond examples such as (18) to sentences with explicitly quantified NP's as subjects, one finds an additional complexity which Witten did not address. This omission on his part is understandable, since all of his examples employ proper nouns or pronouns in the subject position in the main clause.

So, let us now consider an example like (19).

(19) Three valkyries think that Thor ate six oxen.

One may think of the normal/central ambiguity of (19) above in terms of ambiguity in the semantic parsing of the sentence. Intuitively, there are four probable ways that (19) could be parsed semantically, and these readings are enumerated schematically in (20)³⁶

³⁶ Although Witten (1972) does not discuss centrality in terms of semantic parsing, it seems that parsing cues inherent in certain structures underlie many of his constraints and tests for central NP's. For example, Witten's Pseudo-pseudocleft Test instantiates the observation that sentence (a) is not ambiguous even though the sentence (b) is.

- (a) What I believe is I believe Kevin likes three grad schools.
- (b) I believe that Kevin likes three grad schools.

- (20) a. $\text{think} \langle (\text{three valkyries}), (\text{eat} \langle (\text{thor}), (\text{six oxen}) \rangle) \rangle$
 b. $\text{think_that_thor_ate} \langle (\text{three valkyries}), (\text{six oxen}) \rangle$
 c. $\text{think_that_thor_ate_six_oxen} \langle (\text{three valkyries}) \rangle$
 d. $\text{three_valkyries_think_that_thor_ate} \langle (\text{six oxen}) \rangle$

Parse (20a.) corresponds to the Witten's natural reading of (20): the sentence asserts that the two-place *think* relation holds between *three valkyries* and the assertion that Thor ate six oxen. The subject term *three valkyries* scopes the whole expression, while the noun phrases within the complement sentence cannot scope out of that clause. It is expected that the scope ordering of these NP's should vary freely within the embedded clause, and the ambiguity of sentence (21) with regard to its normal reading indicates that this is in fact the case.

(21) Helga said that some Viking owns every longship.

(21) has two normal readings-- one in which Helga asserts that there is one Viking magnate who happens to own every longship, and one in which Helga says that for every longship, there exists some Viking who owns it.³⁷

Confining himself to a purely syntactic approach, Witten does not have an explanation for this phenomenon. Viewed from the standpoint of semantic parsing, it does not seem so mysterious. The context "What I believe is..." seems to cue the parser that the material following is of the semantic form *believe'* (I, x), where x is some expression. This contextual cuing thus forces the normal reading of (b), even though the sentence can be interpreted centrally in isolation.

³⁷Note that central readings can become harder to obtain when both subject and object NPs in the embedded sentence are explicitly quantified. The central reading of (22), in which all NPs are explicitly quantified, is even more disfavored.

(22) Most tourists think that some Viking owns every longboat.

Parse (20b) is an analysis in which the two-place *think_that_thor_ate* relation holds between the *Valkyries* term and the *oxen* term. In this case the two arguments to the relation should have free scope ordering between them, resulting in two scoped forms for the parse. Parse (20c) interprets the sentence as a one-place relation, *think_that _thor_ate_six_oxen* , which takes the *Valkyries* term as its argument. This reading has one scoped form, in which the *Valkyries* term has scope over the entire expression. Finally, parse (20d) interprets the sentence as consisting of a different one-place relation, *three_valkyries_think_that_thor_ate*, which takes the *oxen* term as its argument. This reading has only one scoped form as well, in which the *oxen* term scopes the entire expression.

The question is: which of the three parses (20 b.-d.) corresponds to the central reading of (20)? We can eliminate (20 c.) from consideration since it cannot possibly be construed as a central interpretation of the sentence-- *six oxen* is definitely not a central NP as defined in section 3.3.1. above. So we are left with a choice between parses (20 b.) and (20 d.). The only detectable difference between the two parses is that in (20 d.), *six oxen* obligatorily scopes the formula corresponding to the entire sentence, whereas in (20 b.) there are conceivably two distinct scoped forms-- one in which *six oxen* has widest scope and one in which *six oxen* is within the scope of *three Valkyries* but outside of the embedded sentence. Thus, the question is whether sentence (19) has only one central reading, "There are six oxen such that for each ox, there are three Valkyries such that each Valkyrie thinks that Thor ate the ox,"

The most likely explanation for this preference is that the strong ambiguity of the embedded sentence favors the normal interpretation where the *think* relation holds between *most tourists* and the proposition communicated by the embedded sentence. It seems likely that this is another matter of reading preference, rather than a case where central/normal ambiguity and ambiguity within the embedded sentence are more profoundly incompatible, i.e. that a central reading is impossible if the embedded sentence is itself ambiguous.

whether the sentence actually has two central readings, the one above and "There are three Valkyries such that for each Valkyrie there are six oxen such that for each ox the Valkyrie thought that Thor ate the ox." Put in more general terms, it is unclear whether a central NP, in scoping out of its clause, must obligatorily have widest scope over the sentence as a whole, or whether there is free variation in scoping order between the central NP and the subject NP of the matrix sentence.

One must be careful not to confuse the alternate central reading with a normal reading of the sentence. To verify that they are in fact distinct, let us consider the scoped forms of sentence (19) under the parse (20b.).³⁸

- (21) a. normal (3x, valkyrie(x), think(x, (6y, ox(y), (eat(thor, y))))))
- b. central (6y, ox(y), (3x, valkyrie(x), think(x, eat(thor,y))))
- c. central(?) (3x, valkyrie(x), (6y, ox(y), think(x, eat(thor,y))))

At first glance, it seems that readings (21a.) and (21c.) should be very similar. The only difference between the readings is the position of the quantified *ox* term in the scoped form: in (21a.) this term is embedded within the *think* relational expression, whereas in (21c.) *think* appears within the body of the term. However, this small difference in position makes for a large difference in meaning.

³⁸In this example I have simplified the notation so that the semantic value of the proper noun *Thor* is considered to be a term, rather than a four-part quantified expression. This was done because the analysis of proper nouns as quantified expressions yields two normal readings for sentence (19), both of which mean the same thing:

- (3x, valkyrie(x), (think (x, (6y, ox(y), (thor[z], eat (z,y))))))
- (3x, valkyrie(x), (think (x, (thor[z], (6y, ox(y), eat (z,y))))))

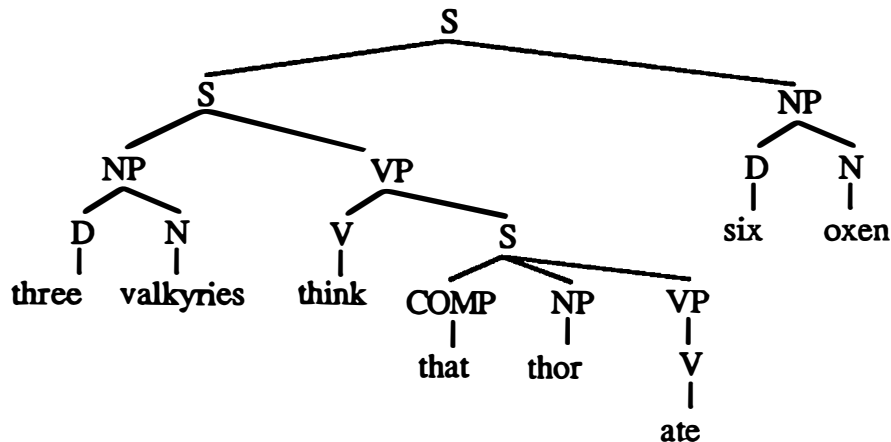
It was thought that this formal scoping ambiguity would needlessly complicate the discussion, since the embedded sentence "Thor ate six oxen" is not perceived as ambiguous.

(21a.) may be paraphrased by saying "There are three Valkyries such that each Valkyrie thinks there is a certain group of six oxen that Thor ate." Since all three Valkyries are thinking the same thing, the sentence entails the existence of only six different oxen. However, the paraphrase of (21c.) reads "There are three Valkyries such that for each Valkyrie there is a group of six oxen such that the Valkyrie thinks that Thor ate the oxen." In this reading, each Valkyrie could be thinking of a different six oxen, thus the existence of 18 different oxen is maximally entailed by this reading.

In light of my own judgements and a little empirical research,³⁹ I see no reason why (21c.) should not be a possible reading of sentence (19). In this case, centrality is associated with parse (20b.) and is a somewhat more complicated phenomenon than one might have been led to believe.

Although Witten(1972) does not consider any examples like sentence (19), one may tentatively extrapolate his position on the question from his syntactic account of centrality. According to his analysis, the central reading of (19) would obligatorily have the following syntactic structure:

³⁹Although time constraints prevented a thorough empirical study of this question, two native speakers were consulted in the course of investigation. One found reading (22b.) obscure, but possible, confirming that sentence (19) could be interpreted centrally. Reading (22c.) was judged to be rather farfetched, and not one which she would associate with the sentence on a first, or even second, reading. The second informant found both (22b) and (22c.) to be perfectly possible readings of sentence (19). However, this informant is a mathematician, which may have biased his response.



Although this is an analysis of the syntax, not the semantics, of the sentence, the structure is highly evocative of the parse (20d.), where the sentence is taken to mean that the one-place predicate *three_valkyries_think_that_thor_ate* is applied to the *six oxen* term. This suggests that Witten's position is that a central NP obligatorily has widest scope over the entire sentence.⁴⁰

3.3. Synchronous TAG Account of Central NP Scopings

In this section, we will be focusing on the scoped forms of sentence (23).

(23) Most tourists think that Odin owns every longship.

We will begin by considering a syntactically naive synchronous TAG for this sentence, depicted in Figure 19. The base formalism for this grammar is the

⁴⁰This is probably being somewhat unfair to Witten, since this condition is absolutely true for the data he considers. However, I will continue to invoke Witten with regard to this point as a convenient way of referring to the position that central NPs must obligatorily have widest scope.

same sort of lexicalized multi-component TAG used in Chapter 2. As in section 3.2. above, we simplify the analysis by treating the proper noun *Odin* as only a term in the semantics. The pairs corresponding to quantifiers are not pictured, but they are identical to the ones used in sections 1.7.3. and 2.3.

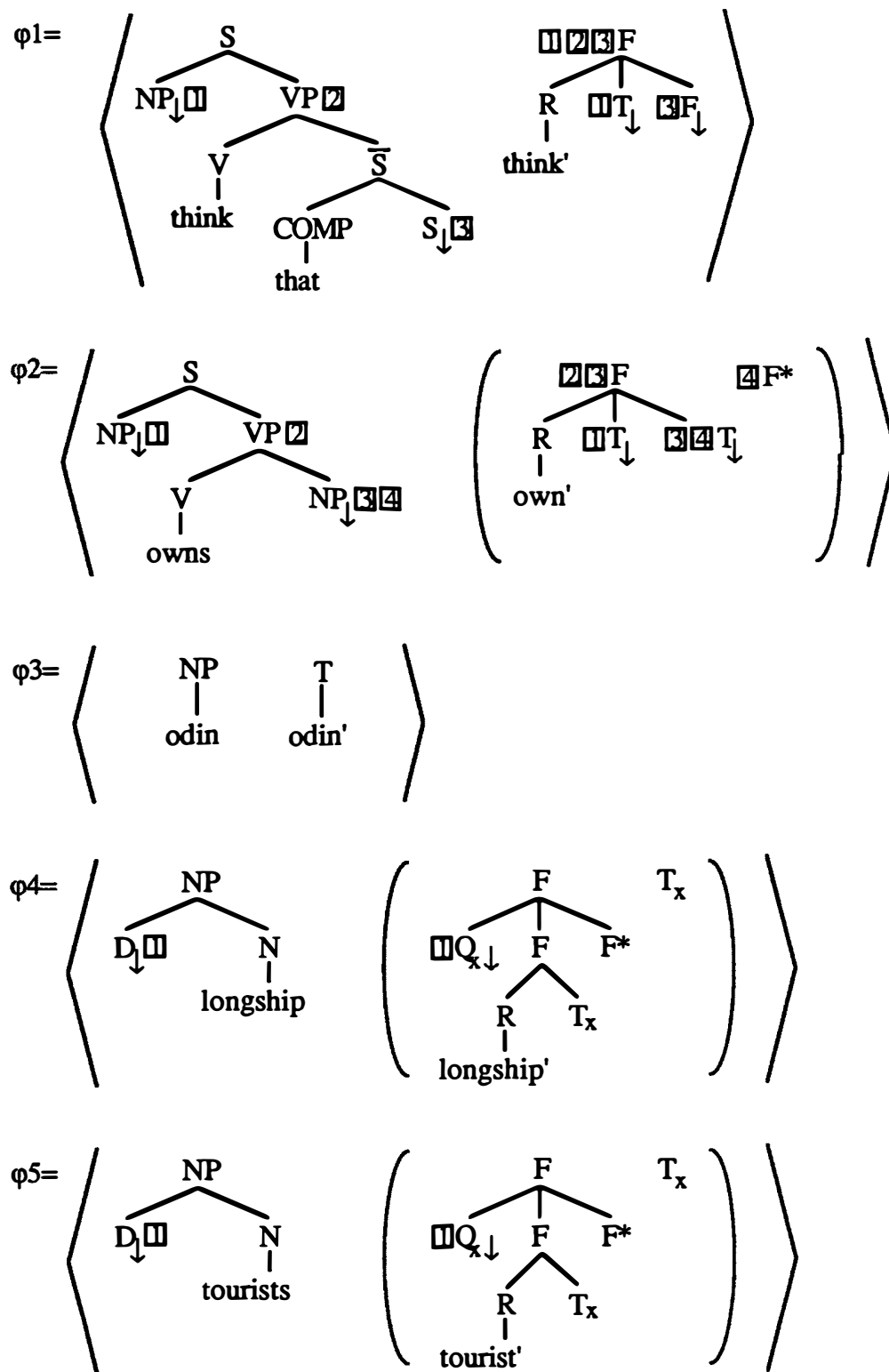


Figure 19: Syntactically naive synchronous TAG for sentence (23)
(quantifier pairs not shown)

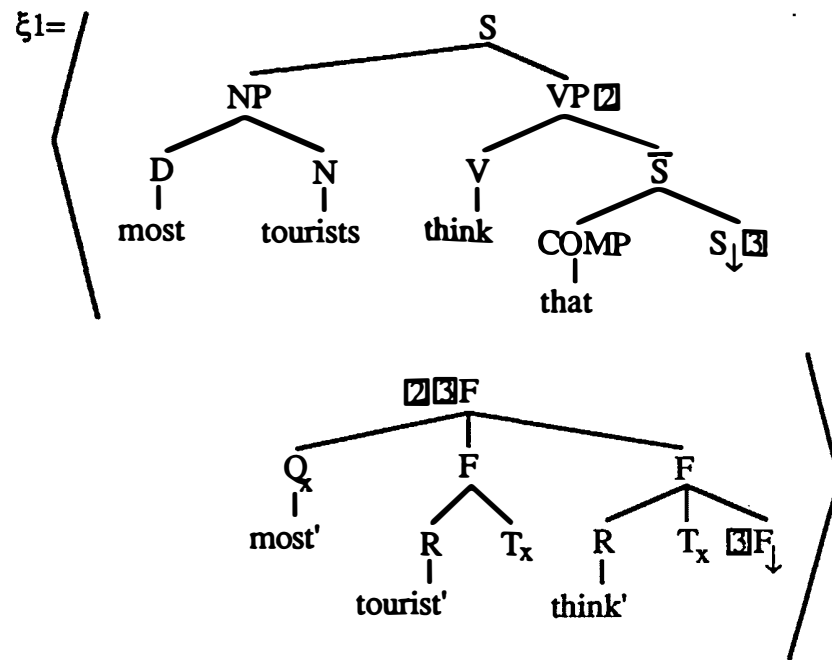
The TAG in Figure 19 is referred to as syntactically naive since it assumes that normal/central reading ambiguity is a purely semantic phenomenon, with no reflex in the syntax. This approach contrasts with that of Witten(1972), but it is proposed in the spirit of streamlining the presentation. Our current interest lies in the semantic aspects of the grammar, which are the same whether or not the central NP is a constituent of the embedded sentence, as in Figure 19, or Chomsky-adjoined to the matrix S, as in Witten's account.

Moving on to the details of the grammar, pair ϕ_1 gives the semantic and syntactic trees for the verb *think*, which takes a sentential complement. Notice that the LF language has been extended to include the formula type for this sort of verb, which acts as a relation between a term and another formula ($F \rightarrow R T F$). The key link to consider in this pair is link 3. In a central reading of a sentence like (23), a quantified expression associated with a noun phrase in the embedded sentence must be able to scope the formula associated with the verb in the matrix clause. Thus, the semantics of the embedded sentence must be in two parts: the formula which is substituted into the formula of the main clause verb and another part which is adjoined at the root of the main clause formula. This requirement is reflected in the specification of link 3.

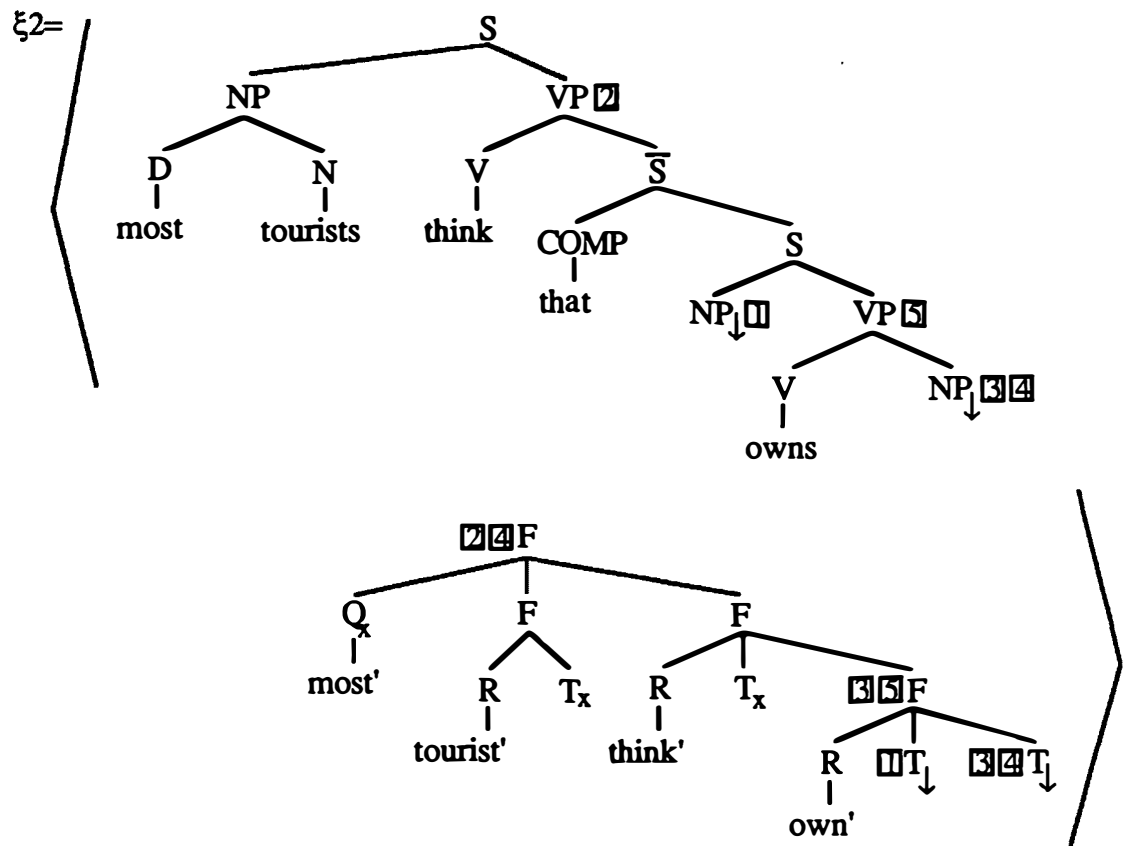
Pair ϕ_2 shows the structures associated with an embedded sentence, with the necessary two-component semantics. This pair is similar to the pair κ_1 given for *own* in Figure 16, but it has a fourth link and an extra semantic auxiliary tree. In addition, it is assumed that the subject NP is a proper noun, so link 1 does not specify the adjunction site for a quantified expression in the left LF tree. The idea behind the fourth link and the extra semantic component is similar to the approach to noun complements presented in

section 2.3. Substitution of the object NP into the syntactic tree can either occur using link 3 or link 4. If link 3 is used, then the quantified expression associated with the NP is adjoined into the topmost F of the left semantic tree. Thus, the scope of the quantifier is contained within the formula of the embedded S, and the reading of the fully derived compound sentence would be normal. If link 4 is used, then the quantified expression associated with the NP adjoins into the right semantic tree, which is always adjoined into topmost F of the matrix sentence semantics. Thus, the NP is scoping out of the embedded sentence, and the reading of the fully derived compound sentence is central.

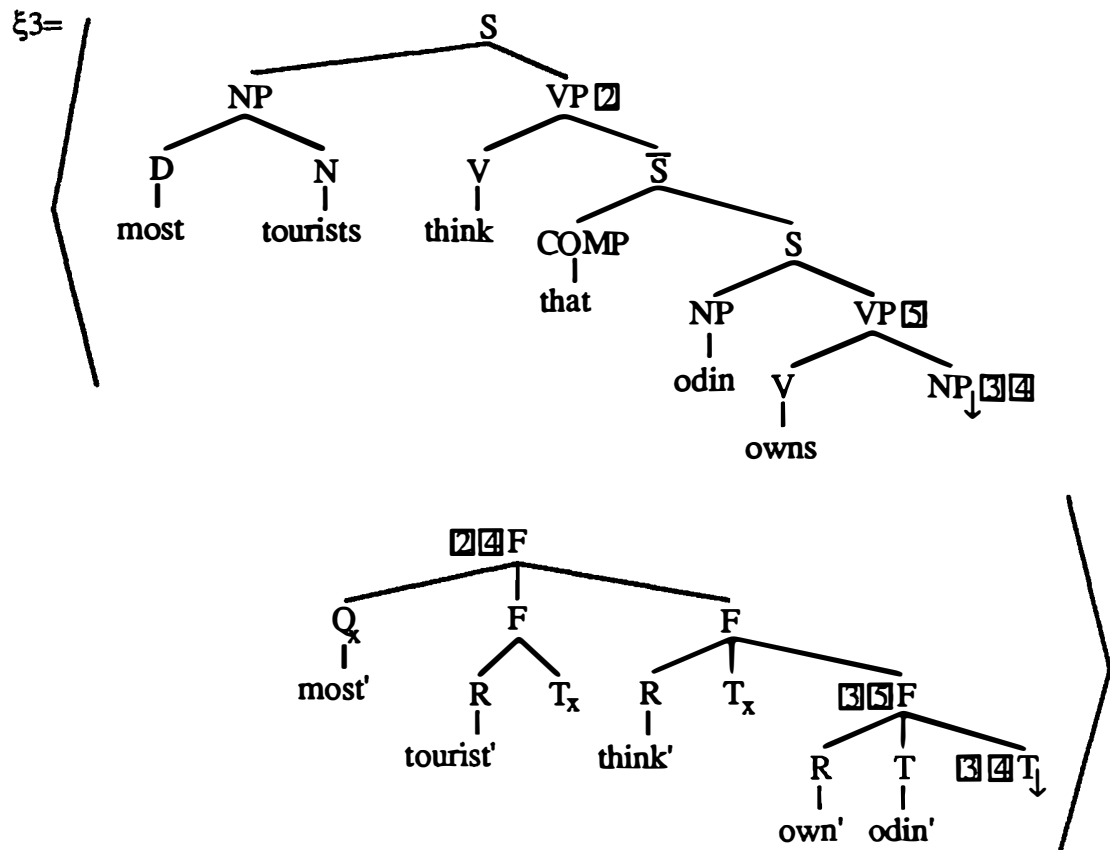
To demonstrate the workings of this system, let us derive the central reading of sentence "Most tourists think that Odin owns every longship," where the NP *every longship* has wide scope over the entire sentence. For this example, we will use the rewriting definition of synchronous TAG derivation. In the interest of brevity, we will not be using the pairs as they appear in Figure 19, but rather derived pairs which already have the appropriate quantifiers inserted. Starting with pair ϕ_1 , we first apply pair ϕ_5 at link 1, yielding ξ_1 .



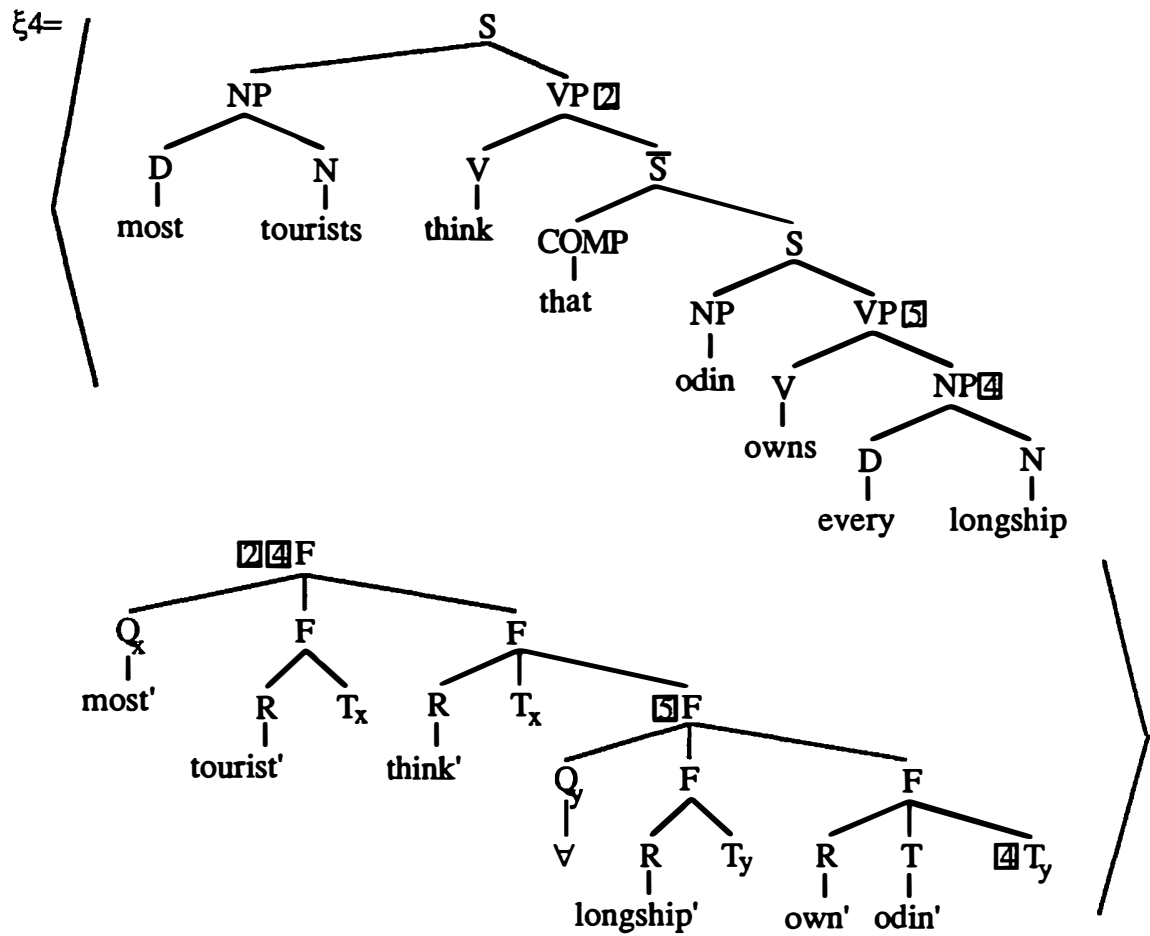
Now, we choose link 3, and apply pair ϕ_2 , yielding ξ_2 .



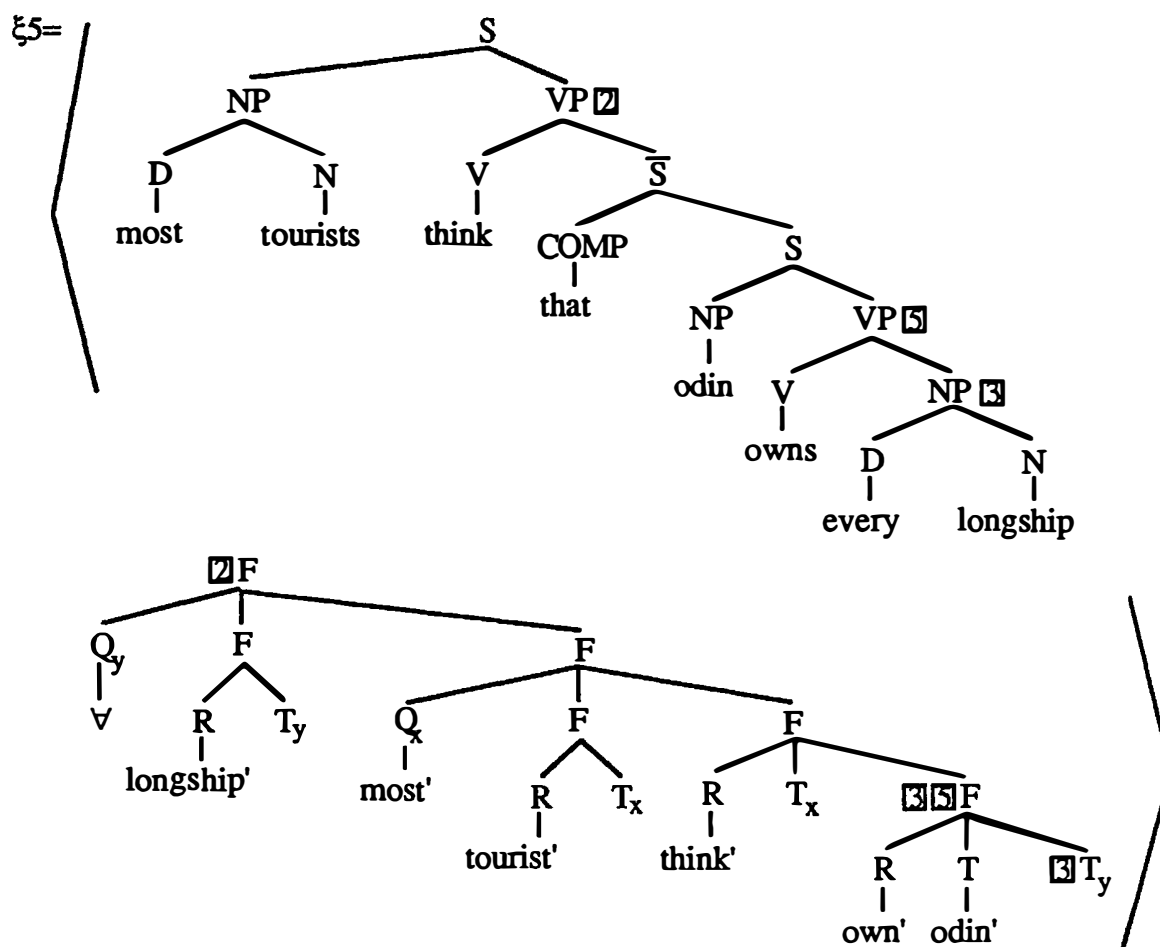
Next, we can choose to apply ϕ_3 at link 1.



At the last step in the derivation, we have a choice. We can apply the pair ϕ_4 at link 3 or link 4. If we choose link 3, then the quantifier \forall will end up within the *think* formula, yielding the pair ξ_4 .



This is the normal reading of the sentence. However, we want the reading where \forall has widest scope, so we will apply the pair ϕ_4 to link 4 in ξ_3 .

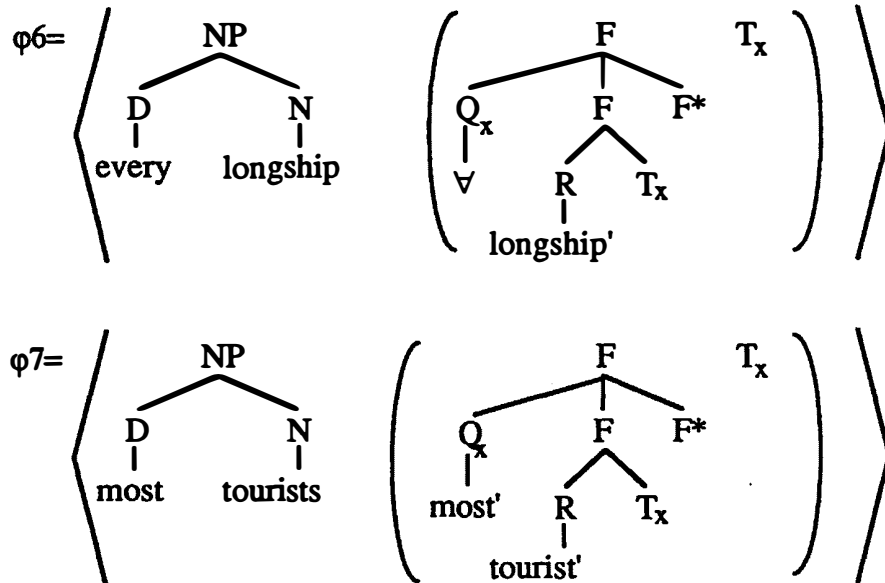


As in the synchronous TAG discussed in section 2.3., the final derived forms have an extra link (3 or 4) which is an artifact of the mechanism allowing choice in the derivation. This may be problematic or not, depending on the level of significance one attaches to links in a fully derived structure.⁴¹

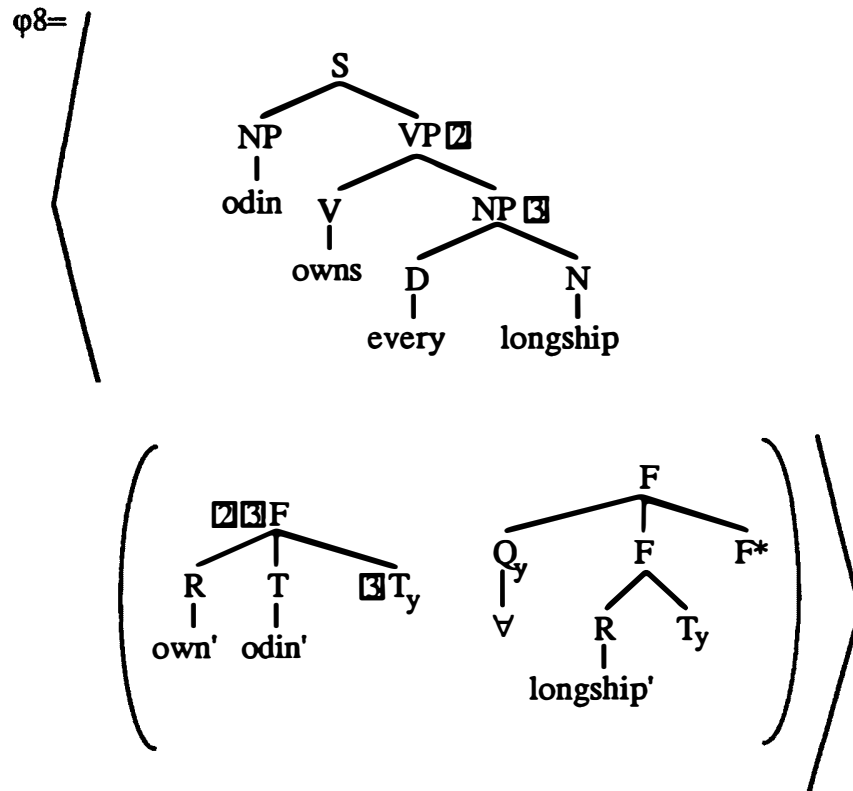
Although we used the rewriting definition of derivation in the above example, we could have used the extended natural definition of Shieber (1992) just as easily. The synchronous TAG of Figure 19 works correctly under either definition. To assure ourselves that this is in fact the case, let us examine the derivation of ξ5 above under the other definition. We will

⁴¹Refer to section 2.3. for a fuller treatment of this point.

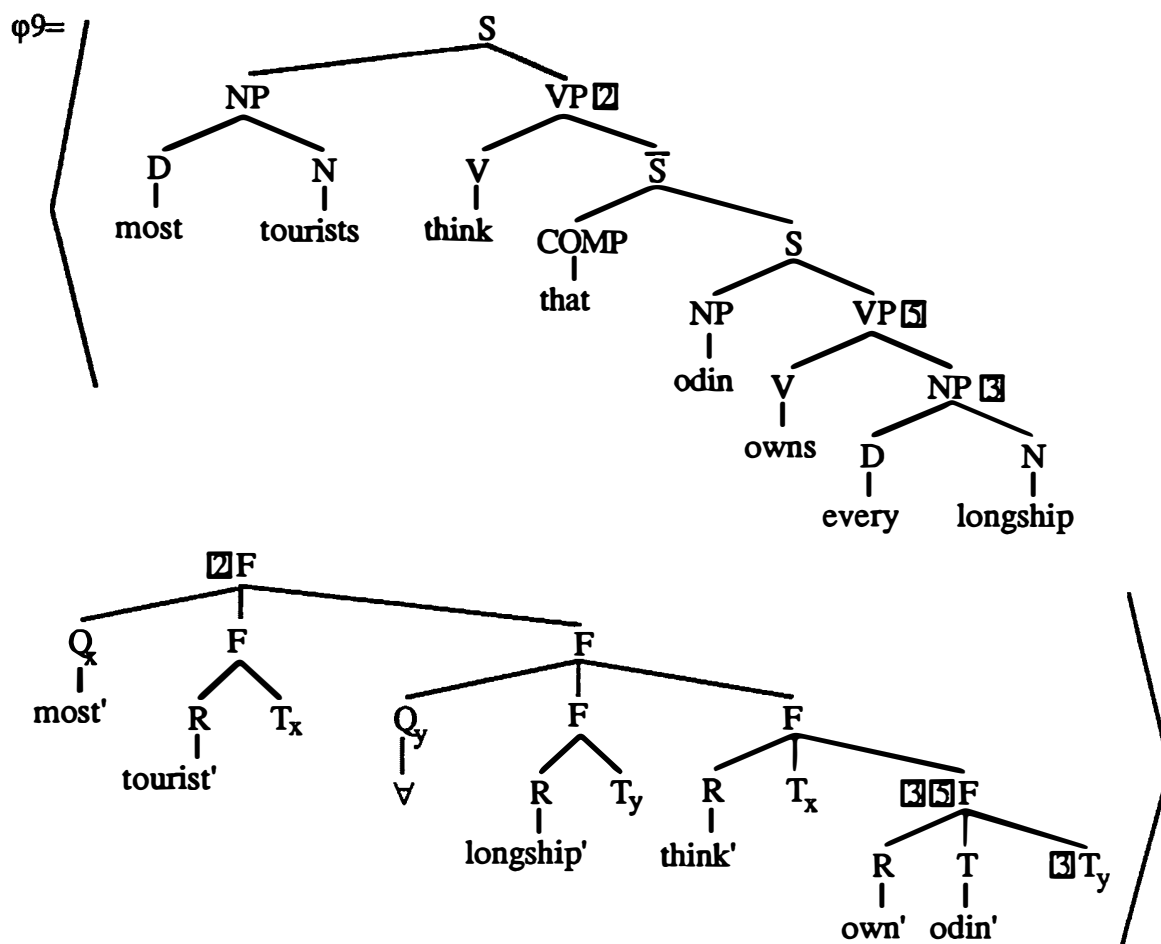
begin by taking pairs ϕ_4 and ϕ_5 and substituting in the appropriate quantifiers, thereby obtaining derived trees ϕ_6 and ϕ_7 .



Now we can apply the derived pair ϕ_6 and the initial pair ϕ_3 to the elementary pair ϕ_2 . Application of ϕ_3 must take place at link 1. Application of ϕ_6 may take place at either link 3 or link 4. We want the reading where the terminal NP has the widest scope, so we choose to apply pair ϕ_6 at link 4, yielding the derived pair ϕ_8 .



The final step in the derivation is applying the derived pairs $\phi 7$ and $\phi 8$ to the initial pair $\phi 1$. $\phi 7$ must be applied at link 1, and $\phi 8$ must be applied at link 3. Adjunction of the semantic trees of $\phi 7$ and $\phi 8$ into the topmost F node of the semantics of $\phi 1$ can be ordered either way. If we order $\phi 8$ before $\phi 7$, then we generate the desired reading,, and the pair $\xi 5$ mentioned in the previous example. If we order $\phi 7$ before $\phi 8$, then we generate the following derived pair $\phi 9$.



This pair is the other "central" reading of sentence (23), the existence of which was posited in section 3.2. Thus, the grammar in Figure 19 as it now stands will correctly generate all of the possible scoped forms of sentence (23) if readings like ϕ_9 are licit. Generation of scoped forms can take place under either definition of derivation. If Witten's (1972) narrower view of centrality is correct even for sentences containing explicitly quantified subjects, then the above reading is forbidden since the central NP must obligatorily have widest scope in the sentence. In this case, the grammar must be constrained further, since it overgenerates by one reading.

Constraining the grammar under the extended natural definition of adjunction is easy since the correct central reading and the spurious reading of (23) are generated by variation in the ordering of two auxiliary trees adjoining at the same node. To force the ordering where the central NP has widest scope, simply place a constraint on the right semantic tree in the LF of pair ϕ_2 such that that tree is always ordered first if it is one of many trees adjoining into the same node. Thus, if derivation proceeds such that the quantifier associated with the terminal NP is adjoined into the right-hand LF tree of ϕ_2 , which always adjoins into the main clause F, then the quantifier will always have widest scope, as desired.

In contrast, constraining the generation of this synchronous TAG under the rewriting definition of derivation is impossible without compromising the definition. Recall that the basic derivational cycle under the rewriting definition is of this form: select any link in a pair, select a pair applicable to that link, apply the pair to the link, repeat. In order to force the obligatory wide-scoping of a central NP, some links must be flagged as having precedence over others. In particular, link 1 in ϕ_2 must be flagged so that it is acted upon before link 3 is. That way, the quantifier associated with the main clause subject is always adjoined first, and so it always falls within the scope of the central NP quantifier, if a central reading is being derived. The simplest way to accomplish such a restriction is to mark link 1 as an obligatory primary link-- if derivation is proceeding into ϕ_2 , then link 1 must be acted upon first of all.

This sort of constraint works, but it directly subverts the spirit of the rewriting definition, which is centered on the nondeterministic choice of any link as the site of derivation at any point. If Witten's position is correct and the constraint is needed, then this constitutes a further bit of evidence that

the rewriting definition is undesirable, since in order to generate the correct forms the restriction must impinge on the core of the derivational process. In contrast, constraint of generation under the extended natural definition was a relatively minor affair, since the process of derivation itself remained unconstrained.

3.4. Summary

It seems likely that the characterization of central/normal ambiguities in Witten(1972) does not capture the whole range of the phenomenon, since he did not consider any examples where the subject of the main clause is an explicitly quantified noun phrase. Thus, a sentence like

(24) Every critic thought Angela made two films.

actually has two central readings in addition to its normal reading-- one in which *two films* has wide scope over the entire sentence, and one in which *two films* outscopes the *think* relation and is outscoped in turn by *every critic*.

A synchronous TAG account can be devised to generate all three readings of a sentence like (24) under either definition of derivation, the original definition or Shieber's (1992) extended natural definition. If Witten's (1972) position that central NPs have to possess the widest possible scope is correct, it turns out that the account can be suitably constrained under both definitions. However, the forms that the constraints must take suggest that the extended natural definition of synchronous TAG derivation is superior to the original definition.

4. Conclusion

This paper has investigated the application of the synchronous TAG formalism to two scoping phenomena in English, with mixed results. After discovering that Witten's (1972) account of central NPs is probably too simple, an adequate synchronous TAG account of central NPs was arrived at fairly straightforwardly. In contrast, scoping ambiguities involving complex NPs admitted of no totally satisfactory account. The account under the original definition of derivation is descriptively accurate, but the formalism is too unconstrained in terms of weak generative capacity. A synchronous TAG properly constrained by the extended natural definition of derivation is not flexible enough to generate all of the possible scoped forms. Further research ought to be done to see if there is a compromise definition of derivation that will be flexible enough to account for the data but constrained enough so that the weak generative capacity of the grammar is kept at the level of the tree-adjoining languages.

In a language as ambiguous as English, there are several problems which were swept under the rug in this paper, including a type of quantifier interpretation which ought to be investigated with regard to synchronous TAGs. This type of "distributive" interpretation is most commonly seen with numerical quantifiers, as in the following sentence⁴²:

(25) Six men peeled 5000 potatoes.

⁴²I am indebted to Kevin Wald for this example.

The preferred reading of (25) is neither the 6/5000 scoped form, in which there are six men such that for each man there are 5000 potatoes that he peeled, or the 5000/6 scoped form, in which there 5000 potatoes such that for each potato there were six men that peeled it. Rather, the sentence is usually interpreted in terms of a set of six men and a set of 5000 potatoes. The sets are related by the fact that for each potato in the set, there is some man in the set of 6 men such that he peeled the potato.

Theoretically then, sentence (25) above has at least three readings-- the two standard scoped readings and the distributive reading above. Devising a synchronous TAG account that could generate not only all of the scoped forms but all of the quantified interpretations of (25) seems to be a reasonable next step in the investigation of the application of synchronous TAGs to natural language semantics. Even if the synchronous TAGs are intended to be used in machine parsing of natural language, these distributive readings will invariably arise and should be included in a full account of the possible interpretations of a sentence.

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Bucky, what could that demented herbalist have meant by 'Some hero antagonizes every villain'? Does this mean that lurking in the shadow of the ample underbelly of night, my nemesis is plotting our no-doubt-unpleasant doom, or is there a arachnid conspiracy of evil which seeks to ensnare us in its sticky web? If only we knew whether some unholy alliance of most villains is lurking in every shadow...

-Suicide Squid, Quantifier Trouble